Hydraulic Research in West Pakistan

By
KHALID MAHMOOD*

I. IMPORTANCE OF HYDRAULIC RESEARCH IN IRRIGATED AGRICULTURE

Water, literally, is life. It was in the deep oceans that life originated in its elementary form and it was on the fertile banks of alluvial streams that man settled to start the chain reaction of civilisation. The pioneering spirit and prolific procreation led man away from the easy sources of water supply. Capricious nature drove him farther and now the biggest problem facing mankind is to find right quantities of right quality water, in right place, at right times. This sounds enigmatic when one considers that three-fourth of the earth's surface is covered with water and the world supply of water is no less than one-eighth percent of the volume of earth. A staggering trillion acre-feet of sweet water are always available in surface streams and lakes and another eighty seven billion acre-feet pour down in rain every year, but humanity suffers from either too little or too much of water.

Apart from drinking and fishing the earliest use of water made by man was for irrigation. The struggle to convey requisite quantities of water at appropriate times has continued throughout the agrarian history of man and will continue with greater vigour for all times to come, unless of course the technology brings about annihilation or a substitute for food as we know it.

West Pakistan depends for more than three-fourth of its cultivated area on irrigation water supply. This is diverted from sources as far away as two hundred miles, through a vast network of canals, having an aggregate conveyance capacity at their heads (including link supplies) of about four hundred thousand cusecs. The economy of the province is primarily agricultural and the development of surface water resources has progressed to the complete utilisation of winter river supplies. The general aridity of the province and its peculiar distribution of rainfall, makes water the most coveted resource. Of the 170 million acre-feet of water that enter the rim stations of Indus valley in an average year, less than one-half is used for irrigation, one-tenth is lost by evaporation or infiltration and the rest is lost to the sea. The need for utilising

**Hydraulic Officer, Irrigation Research Institute, Lahore.*

West Pakistan's share in the flow presently lost to the Arabian Sea presents a huge storage-*cum*-conveyance problem.

With the Water Treaty (1960) seceding the three eastern rivers to India, a gigantic water conveyance problem was created in West Pakistan. This is being solved by constructing two dams, five barrages and eight link canals, which will have a maximum aggregate conveyance capacity of 106,800 cusecs when completed. This combined with forty thousand miles length of existing canals, their twenty-one diversion structures, river training works and thousands of hydraulic canal structures, poses a great maintenance problem, on the successful solution of which depends the present and the future of West Pakistan.

A successful irrigation system needs adequate diversions and their efficient conveyance. To design the diversion, storage and conveyance structures with safety and surety, a lot more needs to be known about the laws of hydraulics than the present store of human knowledge provides. The problems accruing due to this lack of knowledge are neither few nor trivial. They are vital, in fact a matter of life and death for the teeming millions that depend on it. It is in this context that hydraulic research assumes its importance for the 50 million people of West Pakistan.

II. REVIEW OF HYDRAULIC RESEARCH

Research (literally, diligent search) means investigation or experimentation aimed at the discovery and interpretation of facts. This includes revision of accepted theories and laws in the light of new facts and the practical application of new facts. In Hydraulics, as in other branches of physical sciences, the growth of knowledge, has been a result of observation of the phenomena, collection of data, their systematic analysis and derivation of laws interpreting the data. Irrigation, is the oldest branch of applied science and as such, man's need to observe the flow of water, discover its motivating laws and harness it to his well-being was perhaps necessary from the earliest dawn of his consciousness. Yet, the growth of the science of hydraulics from the state of a mere art, has been sporadic and slow, but for the last one century.

(*i*) Historical Review

The earliest beginning of Hydraulic Research, can be associated with the consciousness of man that water flows downhill. Some generalised principles, concerning the laws of flow, must have been deduced by man—whether associating it with planets, demons or gods. Water to the primitive man represented both the benefic and malefic forces. It helped him grow his food and created a barrier between him and his enemy. The malevolent face was the destruction wrought by flood. Water, like sun, therefore always played an important role in the

mythologies. Dsiris was the god of Egyptians who brought fertility to land through his waters. In Greek mythology, Poseidon avenges himself on the three river-gods by drying up all their streams and Amymone placates him into creating the everlasting river Lerna. River worship is known even to this day, in India, and "Playing at Rain" is still practised at the time of drought. When the vast irrigated agricultural systems of Mesopotamia, Egypt, China, India, Inca came up their development must have been on a trial and error basis and what little of theorising they had, besides the mythological gods, has never reached us.

Hydraulic research, as a systematic investigation of the flow of water, can be said to have started with Leonardo Da Vinci (1452-1519). The sketches found in his notes, of the flow over a contracted weir, eddy formation in zones of separation, surface profile at free fall etc., indicate that he had some sort of a hydraulic laboratory, where he experimented. The application of the few laws, discovered by Da Vinci and his successors from north Italy, to the design of hydraulic structures, however, do not seem to have altered the course of engineering, which largely remained dependent on mother wit and constructive instincts. A great change has taken place in the Hydraulic Research since 1875, when Louis Jerome Fargue (1827-1910) made, perhaps the first, movable bed model of a river. The improvement in the experimental technique, the gain in knowledge of facts, and the advance of the science of hydraulic has been immense since then. The seeking of truth by experiments has spurred the advance in the science of hydraulic as in other branches of science. A distinct relation between the improvement of experimental technique and advancement of science can be discerned in the history of hydraulics.

(*ii*) Modes of Research and their Impact

Hydraulic research can be carried out by one or more of the following means : Laboratory experiments, pencil and paper analysis, observation of full scale systems and any other appropriate means. In the past, the pencil and paper, studies led to the abstruse science of hydrodynamics, which was found by practical engineers to be divorced from reality. This almost sublime detachment of the classical hydrodynamics from the needs of practising engineer has been empitomised in "One can go through the whole of Lamb's Hydrodynamics without realising that water is wet". And when the equations of motion for the viscous flow were derived (1822) the exact solutions were not found possible for any but the most simple boundary conditions. The observation of full scale systems is handicapped from the point of view of research. The variables in any natural hydraulic phenomenon cannot be varied at will, to permit a systematic analysis and the size of natural watercourses

is too big for a complete view to be possible at close quarters. The observation of full scale systems in the past, therefore, yielded only gross formulae like the Chezy's or the Regime equations of Stable channels. It is only in small scale hydraulic models in the laboratory, that the variables can be studied in isolation and the phenomena observed in greater detail and range.

The impact of experimentation and observations carried out on small scale models under the controlled condition of the laboratory has been a steady advancement of theory through discovery of more and more generalised laws. The mathematical hydrodynamics which was once the domain of mathematicians, has become a powerful tool in analysis with the advent of boundary layer theory (1904), another result of keen observation on models. From this point onwards, all modes of research go hand in hand. The experiment giving birth to theory, which is tested on other experiments and full scale systems and is further improved, till it can be used to analyse the full scale systems by paper and pencil analysis.

(*iii*) Classification of Research

Like other physical sciences, research in hydraulics can be broadly classified in three domains, depending on the utility of the results sought. These are the fields of Basic, Applied and Specific research. These are defined below but it must be noticed that, unlike the pure sciences, engineering being an applied science with an immense diversity of problems, a water-tight classification of research in engineering may not be possible.

Basic Research is that field of research, where the research worker is looking for a clear understanding of some phenomenon. This phenomenon should be of a fairly widespread importance and the more general the applications, the more fundamental is the research.

Applied Research, is that field of research where the researcher is performing a study or an experiment to shed new light on or to obtain new types of quantitative results for some engineering task.

Specific Research is the research applied to the testing of a particular design problem or other types of problems in engineering practice.

The Basic Research is more akin to academic work, and thrives in the Universities. Applied and specific research on the other hand are usually carried out in the departmental laboratories of developmental agencies concerned with hydraulic engineering. The utility of specific research is more easily recognised than the other two types of research. Its financing is, therefore, not much of a problem and it is most common. In the applied research, the results sought are of a somewhat larger application than to a single problem.

The financing therefore becomes more difficult, as the fund controlling agencies are generally more interested in their immediate problems and unless they can be convinced of the direct applications of the results, they are not willing to contribute to it. The other type of research *i.e.*, basic, is however the one most neglected in all branches of engineering. At one time, all the basic research needed for the development of engineering was carried out in the fields of pure science, and this arrangement worked well. The engineer, who was not interested in anything but the application of science, did not delve into basic research. With the advent of hydraulic laboratories in academic institution, this trend is now changing. It is widely believed that the basic research in engineering should be carried out by the engineers themselves, because of their grasp of phenomena and the knowledge of priorities. Apart from that, the necessity of carrying out basic research within the profession, arises out of the enhancement of profession's prestige and creation of a dynamic attitude which it brings. The training, that basic research provides to the research worker in finding out new, unorthodox and original solutions, is of great help in the other two types of research. Basic research, however, is not generally given its due recognition, is more difficult to carry out and is not readily financed. It is difficult to indicate a direct link between basic research and immediate engineering problems in all cases and thus funds cannot be procured for it from government and engineering agencies alike. (Exceptions to this exist in societies, where the importance of technology is fundamentally recognised). It is often overlooked, that basic research has always found its applications and has always proved of greater long-range benefits than the other two types of research.

III. MODEL STUDY AS AN IMPORTANT TOOL OF HYDRAULIC RESEARCH

The hydraulic research in West Pakistan has been so far limited to specific and applied fields. Basic research is almost entirely absent. In the specific field, the analytic or synthetic paper and pencil studies form a part of engineering design and are thus excluded from our immediate concern. Most of the specific research is thus confined to model studies. Similarly, the applied research, although leading to the derivation of general design criteria, is confined to model studies. The small scale model study, which is based on the principle of hydraulic similitude, is the most important and commonly used tool in the hydraulic research in Pakistan. For applied studies, the technique of dimensional analysis, is used for designing the model studies and this causes a considerably simplifications of the whole process.

(*i*) Hydraulic Similitude

Hydraulic similitude, between a phenomenon on one scale and a similar one, on a different scale, means that results obtained from the one can be scaled to the other. In a strict mathematical sense it implies, that all the forces involved in the phenomenon, like gravity, viscous, surface tension, elastic, pressure etc., are scaled by a constant factor and that the mass distribution in both the systems is similar. Hydraulic similitude can be described, as the similarity of geometry, kinematics and dynamics of the two systems. Absolute similarity between two systems involving similar fluids is impossible to achieve when more than two forces are involved and the limited mechanical properties of available laboratory fluids make absolute hydraulic similitude unattainable, when more than three forces are involved.

The ideal requirements for the hydraulic similitude, however do not inhibit the general practice of model studies. It so happens that in rigid boundary flow, there are in general only two important forces: the pressure on the one hand and viscous or gravity on the other. The gravity forces are generally dominant in free surface flow and the viscous in conduit flow. The expedient then available is to choose model scales, such that the auxiliary forces do not become dominant in the model out of proportion. In such cases the relationship between all the quantities in the two systems can be derived from the special laws of similarity, like Froude, Reynold, Weber, Cauchy etc., depending on whether gravitational, viscous, surface tension or elastic forces are predominant.

In most of the cases involving fluid flow, however, the roughness and turbulence characteristics are important and the basic laws covering these are not fully understood. Same is true of cavitation. In such cases, the similitude sought is of a gross nature. For example, instead of looking for a similitude, between the action of each roughness element or of the magnitude and characteristics of turbulence, the gross similitude of the overall energy head loss and turbulence regime is sought. In some phenomena, involving atmosphere, the turbulence level may become important and may have to be adjusted in the model, to correspond to the effects in the prototype, like separation, transitions in boundary layers etc. The case of a mobile boundary flow is still more difficult. The mechanism of sediment transport and the influence of various parameters on it are not fully understood. There are additional difficulties in the procurement of boundary materials, that will represent the prototype material to the selected scale. These difficulties are, however, overcome as described later. For the utilisation of the technique of hydraulic similitude, it is very important that a good deal is known about the phenomenon under study.

Without this knowledge, and the knowledge of the effect of other forces, which are neglected as an expedient, the result obtained by a model study cannot be considered reliable.

(*ii*) Distorted Models

Although geometric similarity is a fundamental requirement of hydraulic similitude, all hydraulic models are not geometrically similar. In many cases, especially of the phenomena involving mobile boundaries, the distorted models, in which the geometrical scales in different planes, or of different components are different, are a rule rather than an exception. This is necessary for duplicating the bed movement and scour in the model, as well as achieving a turbulence regime similar to the prototype. In some other cases, the components of structures may be distorted, so as to compensate for the difference in boundary layer growth, or the difference in the energy gradient in the two systems. The distortion of models however is essentially dictated by the restrictions imposed by the available laboratory facilities.

Since the distorted model does not have complete kinematic similarity with its prototype, its results have to be interpreted with caution.

(*iii*) Dimensional Analysis

In the basic or applied research studies, where the relationship between the parameters involved in the phenomenon are not known, the technique of dimensional analysis is used for considerably simplifying the investigation. This technique does not obviate the knowledge of the mechanics of the phenomenon, nor does it provide any indication of the relationship to be expected. Its major utility lies in reducing the number of variable physical quantities and in the combination of the physical quantities into groups which are more meaningful about their effects.

(*iv*) Model Verification

In most of the models of rivers, involving mobile boundaries, the phenomena involved are too complex to be related to only two dominant forces. The details of the phenomena and the effect of physical variable involved are also not fully known. These models, moreover, have to be almost invariably distorted to represent bed movement and bank scour. It therefore, becomes impossible to rationally derive the model scales or to satisfy the similitude requirements between the two systems. This difficulty is resolved by the principle of model verification. The earliest recorded statement of this principle was made by Vernon Harcourt (1889) as below :

> If I succeed in demonstrating with the model that the originally existing conditions can be reproduced typically; and if, moreover, by placing regulating works in the model, the same changes

can be reproduced that were brought about by the training works actually built, then I am sure that I can take the third and most important step, namely, of investigating with every promise of success, the probable effect of the projects that have been proposed.

In practice, the horizontal scales and distortion are fixed by the experimenter, on the basis of his experience and judgement. The model is moulded on the basis of a past survey and other scale ratios like the discharge ratio are fixed as a first approximation by the modified Froudian similarity law. Ratios like time scale are again selected on the basis of past experience. A known hydrograph of the prototype is then run on the model and the effects on the model channel are compared with the prototype. Usually the distortion and the scale ratios have to be adjusted till the model behaviour corresponds to the observed prototype behaviour. When this has been achieved the model is said to have been verified. The proposed works can then be introduced and studied. In general the mobile bed model studies suffer from an over representation of higher than the lower stages. Similarly the silting cannot be adequately reproduced at the time scales required for scouring. These facts may necessitate the use of a sliding time scale and artificial silting of models. It may be seen that the principle of verification is derived from intuitive reasoning, as such the reliability of results obtained from the method will depend to a large extent on the adequacy of prototype data, experience of the worker and the time available for such studies.

The limitations inherent in such a model study are generally not well appreciated. The most important condition in the verification process is that the type and range of the phenomenon used in the verification sets the limits of the proposed study on the model. Thus if a model has been verified for an occurrence of bank scour over a full year's hydrograph containing a bankful discharge, it can be legitimately used only for the study of bank scour within this range of discharge. The verification of a model by attaining gauge-discharge relationship cannot be used for this purpose. If these limits are transgressed, the reliability of the results obtained becomes doubtful.

The process of model verification is a trial and error procedure from which the model scales are derived. The accuracy of the method hinges on the reliability and extent of the field information available.

(*v*) Object of Model Studies

The model studies in hydraulic research are generally carried out for one or more of the following objectives :—

(1) *To obtain basic information about the laws governing certain phenomena.* This is the case generally applicable to basic studies, *e.g.*,

study of turbulence characteristics downstream of a hydraulic jump, turbulent flow in porous media, unsaturated flow in porous media, growth and behaviour of boundary layers, sediment entrainment by flow, etc.

(2) *To test the laws proposed for certain phenomena.* This again is a basic study objective, whose examples are verification of the pressure-momentum equation for hydraulic jump, resistance characteristics of different shapes and spacing of resistance elements, etc.

(3) *To derive the design criteria for a given type of structure.* This is an applied research subject and may be a synthesis and extension of the data previously obtained, with respect to the performance or efficacy of a typical structure. It may include effect of shape of pier on scour characteristics, standardisation of stilling basins or stilling basin appurtenances, efficacy of different spur dikes, silt excluders etc.

(4) *To test the application and validity of certain instruments and laboratory techniques.* This is a part of the basic research and may consist of the study of effect of the shape of piezometric taps on the recorded pressure ; effect of the length and type of connecting tubes on the indication of transient pressures ; the utility of measuring devices like shear tubes ; standardisation of velocity tubes, etc.

(5) *To solve problem arising during construction.* A currently popular use of model studies in specific research is to find solution of construction problems like planning, cofferdamming, diversions etc. For such purposes a model of the proposed work is maintained throughout the construction of the project and the problems are tested as they arise.

(6) *To test the relative efficacy of remedial schemes, where the laws governing the phenomenon are not well known.* This is primarily a specific research case, and the example may be cited of the bank protection dikes. The alluvium, in which a stream flows is usually heterogenous to an unknown degree and the mechanism of bank scour for such cases is not fully understood, nor can it be resolved by a paper analysis. In such a case, the model duly verified for a bank scour data is the only reliable tool available to test the efficacy of any given scheme of remedial works. This use of the model is like a computer, which once verified is assumed to synthesise all the variable involved in providing the final answer.

(7) *To solve the problem, for which the analytical solution is too difficult to perform by paper and pencil.* This is a very common use of models in both applied and specific research. The examples for this may range from the determination of free streamlines to the efficacy of proposed training works. The solution of the former problem is available by the methods of transformation, relaxation and freehand flow net sketching. But the absence of known solutions or labour saving devices like computers, a simple model test usually provides the quickest answer. In the case of proposed training works for bank protection or sea wave dampening, the analytical solution can be highly cumbersome as compared with a model study. The case of overbank flow in a stream is another case in point. The accuracy of both the paper and model analyses will depend on the adequacy of information available on the cross section, bed, bank and over bank roughnesses, etc., but the model will generally provide a quicker and cheaper answer, with the added advantage, that the whole process can be viewed directly, with a consequent ease in the suggestion of remedial measures.

The last two objectives of model studies are the most widely adopted in practice. Some basic information about the processes involved and ample field data are most essential for their successful achievements. It may be remarked in passing that this use of the model studies in hydraulic research is so handy, that it is even considered by some to be hampering the advancement of theoretical knowledge.

IV. ORGANISATION OF HYDRAULIC RESEARCH IN WEST PAKISTAN

Hydraulic research in West Pakistan is presently confined to public sector alone. Almost all the research is carried out in the Hydraulic wing of the West Pakistan Irrigation Research Institute. The West Pakistan University of Engineering and Technology has set up a new hydraulic laboratory in its civil engineering department, but a regular research program has not yet been initiated. The two other engineering colleges in West Pakistan, namely at Peshawar and Karachi are also not active in this field.

The Irrigation Research Institute is an integral part of the Irrigation and Power Department of the Government of West Pakistan. It is administered by the Secretary, Irrigation and Power through the Director of the Institute. The work of the Institute is split in seven specialised wings : (1) Hydraulics, (2) Soil Mechanics, (3) Engineering Physics, (4) Ground-water Hydrology,

(5) Statistics and Mathematics, (6) Instrumentation and (7) Publication. Besides these wings, the Institute is maintaining two electrical-mechanical workshops, one at Lahore and the other at Nandipur. The instrumentation section has its own workshop in the laboratory at Lahore. Besides this Laboratory, the Institute has four field research stations, at Nandipur, Hyderabad, Karachi and Niazbeg. The first two stations are exclusively dealing with the Hydraulic of surface flow ; the one at Karachi is mainly a soil mechanics and engineering materials' laboratory, but also deals with hydraulic problems. A wave generating flume has recently been added there, and it is planned to develop its hydraulic section for coastal problems exclusively. The Niazbeg station is essentially dealing with the seepage control and evapo-transpirational studies. The Institute has its main library at Lahore with about forty thousand volumes covering many fields in Civil Engineering. Small libraries exist in various sections and at the field research stations. In addition, the staff of the Institute is eligible to use the PWD Library located in the closeby Irrigation Secretariat building.

The work done in the Institute falls in two broad categories : (1) Specific research for Irrigation Department and other agencies including West Pakistan Wapda, (2) Applied and Basic research work on direct grants from the Government of West Pakistan. For the specific work, the actual cost of the study is charged from the sponsoring agency, except that departmental charges of 27.5 percent of the cost are levied on agencies other than the irrigation department. This charge is, however, directly credited to the Government and is adjusted in the accounts of Director, Audit and Accounts, Works, West Pakistan. For the Indus Basin Plan studies, a special agreement controls the work, under which the Indus Basin Project pays for the direct cost of some employees and the actual cost of its studies plus a nominal pro-rata charge. The latter charge is again neither credited to the Institute nor controlled by it. The applied and basic research work is financed by the Government of West Pakistan out of its annual budget. The acceptance of the proposal of studies and the budget allocation is controlled like any other work of the department.

(*i*) Historical Review

The history of the development of Irrigation Research in West Pakistan, has already been traced(1)*, and will only be recounted here in brief.

Hydraulic research in West Pakistan regularly started in 1924, with the appointment of a scientific research officer, in the Irrigation Branch of the Public Works Department of the then province of Punjab. The irrigation

---

* Numbers in parentheses refer to items in the list of references at the end.

system which then existed had already created problems of waterlogging and salinity. In addition there were operational problems like those of distribution, subsoil flow, silt conduction, seepage, river training etc. etc. These problems were peculiar to the province of Punjab and the development of irrigation had progressed so rapidly that the engineering science had not kept pace with it. The necessity of a research organisation which could provide investigation into these problems had been stated early as 1915(2). The matter was discussed and recommended to the Government for nine long years before a nucleus was established with the appointment of Mr. B. M. Wilsdon as the Scientific Research Officer. The laboratory was housed in a wing of the Panjab University Chemical Laboratories, from where it shifted to the present building in the PWD Secretariat block in 1928. A hydraulic field research station was established at Malikpur near Pathankot (now in India) in 1931. The soil survey and cement testing laboratory was added in 1943 and the Directorate of Land Reclamation was separated in 1945. After Independence, a hydraulics field research station was established at Joyanwala but it was later abandoned in favour of the present station at Nandipur in 1951. The Niazbeg Station was established in 1959 and the Karachi and Hyderabad Stations were transferred from the Central Government in 1963.

(*ii*) Growth Since Independence

The physical growth of the Institute, since Independence, has been stated in brief. The growth now under review, pertains to that of the staff and output of the Hydraulic Wing of the Irrigation Research Institute. Data in this respect have been collected from the records of the Institute and are tabulated in Tables I and II.

Growth of Staff. Soon after Independence, the Hydraulic Wing had one Research Officer, two Assistant Research Officers and nineteen Research Assistants (in A, B and C grades). This position continued till about 1960, with the number of Assistant Research Officers increasing to two in 1948 and three in 1959. In 1960, a Class II post was added. The next year saw the addition of one senior class I post from IBP. In 1962, ten class II and two senior class I posts were added, all financed by the Indus Basin Program. Another seven junior class I and two senior class I posts were added in 1963 and two senior class I posts were added in 1964. Sixteen class II posts of Indus Basin program were upgraded to junior class I in 1963. This growth of staff is represented in Fig. I by two curves. The curve for gazetted establishment includes Assistant Research Officers, Research Officers, Senior Research Officers and Principal Research Officer. The curve representing the total establishment includes non-gazetted Research Assistants

besides the gazetted establishment. Supporting staff like observers, laboratory attendants etc. are not included in this. From this figure it may be seen that the ratio of gazetted to non-gazetted staff, increased from about one is to ten in 1948 about three is to one in 1965. This signifies the improvement in the pay scales of research workers in the Hydraulic Wing since Independence.

Growth of number of model studies. For a major irrigation Project, the Institute may have to carry out about six different studies for the various aspects and components of the project. For smaller projects or individual problems, a single model study alone may be needed. The number of model studies, however, represents the physical work load of the Institute. The number of model studies in progress in a year has been plotted against the various years of the post-Independence period in Fig. II. Two curves have been drawn in this figure ; the lower for the basic and applied studies and the upper for the total number of studies. The ordinate between the two curves represents the number of specific studies. In addition to the model studies, the Institute also undertakes paper studies and review of designs and reports, which undoubtedly add to its work load. The quantum of work involved in such paper studies is however indeterminate and, as such, has been excluded from this figure.

The major enhancement of the work load, in 1961-65, has come from the Indus Basin Problems. The insignificance of applied research work in comparison with the specific research can be noted from this figure. Strictly speaking, no basic research model study has been explicitly undertaken.

The total number of the research personnel in each year is also shown on this figure. An important conclusion can be drawn from the data presented in this figure : The increase in the number of all gazetted and non-gazetted research workers is seen to lag behind the work load by about four years. This is a lucid indication of the lethargy that has been experienced in getting additional staff sanctioned and signifies the delay in recognition of the importance of research, which also marked its beginning.

Growth of number of reports. The work done by the Institute is reported in the form of technical reports. Other reports like monthly and annual reports are also issued, which are a compilation of the work done during their respective periods. The technical report issued on a problem under study, may pertain to a paper or a model study and may mark the completion of the study or that of an important phase of the study. It may thus be an interim report. For major projects and long drawn out studies of complicated problems quite a few interim reports are issued before the final report. The number of technical reports issued, therefore, provides a good index of the output of the Institute. The yearly number of technical reports issued by the

Hydraulic Wing of the Institute is plotted in Figure III. The annual position of the research personnel is also shown therein. The time lag between the increase in the number of personnel and the output may again be noted. This signifies the increased pressure of production on the research worker. A more clear indication of this pressure is however presented by Fig. V.

The cumulative number of technical reports since Independence has been plotted in Figure IV. This curve depicts the continuous growth of output of hydraulic research in the Institute. It may be seen that about five hundred technical reports have been issued by the Hydraulic Wing since Independence. The rate of output which, in the first four years of the data has been eleven reports per year, has increased to thirty-eight reports per year in the last four years.

Growth of work load per worker. The quality of output in research is inversely proportional to the work load on a worker. The literature research, model design, model verification, model study and finally the analysis of data, all require a patient and time-consuming effort. A cramped research program, wherein the worker is not only overloaded but also pressed for results, needed yesterday, leads to a sacrifice of the quality of work produced. It is, therefore, important to study the work load on the research personnel during the post-independence period. The index adopted for the purpose is the number of both gazette and non-gazetted research personnel per model study. The paper studies have been omitted on account of the indeterminancy of their work load. The number of model studies rather than the number of technical reports has been adopted, as the quantum of work load cannot be represented by the latter. The data have been plotted in Figure V. It may be seen that the number of research personnel per model study has diminished from 3.67 in 1949 to 0.48 in 1964. This means that the workload per research worker has increased by more than 7.5 times in the sixteen years from 1949 to 1964.

This figure also shows the number of IBP research personnel per IBP model study. The curve is all along lower than the average for the Hydraulic Wing and indicates that the contribution of IBP towards the research personnel was not commensurate with their work load.

Indus Basin Research. The Indus Basin Replacement Plan was formed to replace the supplies seceded to India under the Water Treaty of 1960. The construction of two dams, five barrages and eight link canals, at an estimated cost of ten billion rupees, is one of the largest civil engineering undertakings. The specific research program pertaining to this plan, has a correspondingly vast magnitude. Barring a few studies which were undertaken at the foreign laboratories, the whole of the Indus Basin Research program has been handled by the Irrigation Research Institute. This has been a stupendous undertaking

and is being carried out under a special arrangement with the World Bank and the West Pakistan Wapda. The successful execution of this research program provides an index of the capacity of expansion of the hydraulic research in West Pakistan. Yearwise data pertaining to the number of model studies in progress, the number of technical reports issued and the number of research personnel directly financed by the Indus Basin Research program have been plotted in Figure VI along with the total numbers for the Hydraulic Wing for the period 1961-65.

These figures show that a maximum of eighty-five per cent of the total number of specific model studies in progress at any one time were devoted to IBP research and a total number of 112 technical reports, constituting more than half the number of total reports issued by the Hydraulic Wing in this period (1961-65) related to IBP research. No basic or applied study was financed by the Indus Basin Project. These figures further show that the IBP research is contributing about one-half of the gazetted and non-gazetted research personnel employed in the Hydraulic Wing of the Institute.

Two important conclusions can be derived from this data. The first relates to the past performance of the Institute and the second, to the future of the research organisation which has been created as a result of the IBP research. The Hydraulic Wing of the Institute can be rightly proud of its performance in handling the IBP research program and thus exhibiting a singular capacity to expand itself. In future, however, the number of model studies in the Hydraulic Wing is likely to diminish rapidly with the reduction in Indus Basin workl ad. The staff charged to the IBP research will have to be correspondingly reduced. This implies losing research workers, who have been trained for two to four years and thus dissipating the research potential that has been developed in 1961-65. It is important to the Institute and is vitally important to the national interest, that this research potential be maintained and utilised to satisfy the research needs, which have of necessity been neglected under the strain of developmental and IBP research.

V. PROBLEMS FACING HYDRAULIC RESEARCH IN WEST PAKISTAN

Hydraulic research in West Pakistan has considerably expanded since Independence. An almost phenomenal increase in the workload and output of the Hydraulic Wing of the Irrigation Research Institute took place during the years 1960-65 (Figures I through IV). The major spurt came as a result of the Indus Basin Research program, which was undertaken in almost its entirety by the Institute. A reorganisation of the Institute has also been started in the second Five-year Plan. The facilities of staff, laboratory space and equipment have, consequently, improved over the past few years.

A National Research Council has been recently (1964) established in the field of Irrigation, Drainage and Flood Control. This is an indication of growing research consciousness on the national level. The possibilities of further improving the research standards and expanding the research activity should now be greater than ever before. The hydraulic research in West Pakistan is, however, suffering from some problems. These are the problems of staffing, programming and financing the hydraulic research. It is important to discuss these problems here, because of their paramount importance in the context of both the existing research effort and its future development.

(*i*) Staffing

The basic problem facing a research organisation in any discipline is that of the number and quality of manpower. It has been estimated (3) that a 3 to 4 percent fresh annual recruitment is needed to maintain the existing levels of research activity in scientific disciplines. If the scientific and technological research, has to keep with the expansion in the economy and technology, another 6 to 10 percent annual recruitment is needed. A total of 10 to 15 percent fresh recruitments in the research organisations per year are thus indicated. In the field of Hydraulic research, this may seem a modest figure, when the accumulation of problems over the past few decades is also considered. In a developing country like Pakistan, where the educational facilities and output are lagging behind the needs of various physical and applied science disciplines (4), attracting this number of qualified personnel to the field of hydraulic research can be problematic. The quality of research workers, as in any other scientific discipline, is also of vital importance in hydraulic research. The requirement of first rate qualified men who are dedicated to their jobs and are satisfied with their working conditions and economic prospects, makes the problem of adequate recruitments still more difficult. The present state of the problem is that the field of hydraulic research is not sufficiently attractive, as compared to other pure and applied science occupations including engineering. And when this is viewed in the overall situation prevailing in Pakistan, where the technological field is overshadowed by the prospects in many non-technical vocations, especially the Civil Services, the position becomes still worse.

Motives for career adoption. A man may select a career for economic motivation alone, up to the fulfilment of his bare material needs. Beyond this limit, the motivation may be a combination of economic prospects, social recognition and innate inclinations, each accentuated to a particular degree depending on the nature of the individual. It is understood that for the research worker, the bare economic provisions can be met with in any vocation, because of his basic academic qualification. What remains is the ultimate motivation, that brings him to the field of hydraulic research. This field may be intellec-

tually challenging and emotionally satisfying, but money-wise it is at present a poor field to choose. The limited cadres, restricted pay scales, absence of economic incentive and lack of facility for improving academic qualifications make hydraulic research an unattractive field compared to other field in engineering*.

Men will do a great deal for their social recognition. The evolution from a general state of dependency on the social admiration to the higher plane of disregarding this admiration in favour of individual judgement does not touch very many**. The mortals are thus verily guided in their choice of careers by the approbation that society bestows on them. Unfortunately, at the current stage of sociological evolution in Pakistan, the scientist and technologists are not granted a duly favourable recognition.

The best and the most important motive for a research worker, are his innate tendencies. A person born with strong instincts of curiosity and self-assertion, with a favourable influence of early training, will generally work into the field of learning and research. But here hydraulic research has to contend with many other fields of social and physical sciences to attract the prospective individuals. Thus, the economic and egoistical motives alone become important factors in the final analysis.

Attracting suitable talent. In order to maintain the existing tempo of research and to cater for the expansion required, it will be necessary to attract many more engineers in this field. What can be done for this? The answer is not easy to seek. There are some factors, which cannot be manipulated at present. The status of the research worker in the social order cannot be artificially boosted by this forum. But there are some steps that can be taken to make this field more attractive.

(1) Facility for Academic Qualifications :

Research workers, should be provided with opportunities to achieve higher training and academic qualifications. The occupation in research entails a continuous improvement in the theoretical knowledge and research techniques to some extent. But the store of knowledge in hydraulics research is expanding at such a fast pace, that it may be doubling every

---

* It had long been accepted, and Greek thought has bestowed this legacy, that higher learning and material well-being should not go together. For the idealist, a plea for material incentive for a research worker may thus seem abhorrent, but the world has changed a lot since the time of Plato and Socrates.

** "God in His great Wisdom has afflicted only a few with this burden (of the need to know and to create), and man in his lesser wisdom has denied many of these few the opportunities for development they need."(5)

10 years. Busy working schedules and pressure of immediate problems occasioned by under-staffing*, usually do not allow the research workers to follow even a small portion of the advancement in their fields, however narrow their fields may be. It would thus be advantageous to the research program as a whole, if the research workers are given study leave once every five years or so, for devoting to advance learning exclusively. The attraction that this chance of self-fulfilment provides to the individuals is known to be substantial.

(2) Pay scales:

The pay scales of the research workers should be kept somewhat higher than the corresponding positions in other fields of the engineering profession. The economic incentive is essential to attract talent to the field of hydraulic research.

(3) Promotions:

A system of regular promotions may be introduced in the research Institute. Once a person has entered a profession, he will look for a sense of security in the job and for a prospect of steady rise. The hydraulic research in West Pakistan being entirely government controlled provides ample security of service, but the prospects of steady rise are dim because of limited cadres. It is not unusual for a research worker to stay in one grade of pay for many years. This naturally makes the profession unattractive for new entrants and for the present incumbents, detracts from their interest in the job. It is, therefore, necessary to provide flexible cadres, wherein the number of higher posts can be expanded, to provide opportunities of regular promotions.

(4) Private Practice:

Private practice should be allowed to the research workers. By virtue of his specialised training, the research worker in hydraulics is frequently called upon to give professional advice, by private agencies and other departments. This activity is beneficial to the worker from a professional standpoint, because it introduces him to problems out of his routine job, and thus broadens his outlook. The economic advantage that can accrue to the research worker on this account can be an extraordinary incentive, without any

---

* Notice: time lag of about four years between peak load of model studies and maximum staff strength in figure II, and also that the work load per research personnel in the hydraulic wing—IRI, has increased seven and a half times, from 1949 to 1964.

expenditure to the government, so long as the work is confined to outside of normal working hours. Presently, the sanction for such private consultation is regulated by omnibus rules, which cater for all other branches of the engineering profession in the government, and thus, are necessarily restrictive. Rules can be specially framed for the research workers, somewhat on the line adopted in the medical profession.

(*ii*) Programming

The second important problem in the present context is that of the formulation of research policy and programs. Most of the work so far done in the field of hydraulic research in West Pakistan, falls in the category of specific studies, which are concerned with the problems of a narrowly limited range of applicability. This has been occasioned by the shortage of staff and facilities which could not be expanded corresponding to the developmental activity. For the period 1947-1965, in the hydraulics division of the Irrigation Research Institute the percentage of applied research studies amounted to only four per cent (Fig. III). The number of basic studies was nil. Barring the inclinations of individual workers, no set program of research could be followed by the Institute. The number of problems facing the Irrigated Agriculture of West Pakistan are many, the gaps in the knowledge of laws controlling the flow of sediment-water complex are wide and the occupancy of the flood plains presents a constant threat to the survival of millions. All these problems cannot be taken up simultaneously (for want of resources, trained personnel etc.) and have to be pursued under a system of priorities. Before that can be done, all the problems awaiting solution have to be laid down.

Problems awaiting solution. The delineation of research needs, in West Pakistan, brings us to a major issue, *viz.*, that of the profession's participation in research. Without detracting from the service rendered by the Irrigation Research Institute in the past and the dedication exhibited by the research workers engaged on the job it can be said that the research needs are most apparent to those who are involved in operating, designing and planning the water resources. They are the people most competent to draw up the needs in hydraulic research in West Pakistan. Unfortunately, the participation of the profession in this work has been so far inadequate. It is necessary for the agencies concerned with the land and water resources, and the technical societies representing the profession to get together in the form of a high powered council* and elicit problems from the practising professional engineers. The

---

* A Provincial Research Council, on the pattern of recently established National Research Council, is proposed later in the text.

survey of our research needs can thus be completed. With this statement before, it, the council can go into the problem of available finances, man-power and into the priorities. Unless this is done, a systematic and fruitful approach to the problems of research cannot be made.

(*iii*) **Financing**

The most crucial problem, facing the hydraulic research in West Pakistan is that of finances. As discussed earlier, the funds can be more easily procured for specific studies, than for the applied or basic research. The agency interested in the study of its immediate specific problem is usually willing to pay for it. It is in the applied and basic research field that the funds are not forthcoming. It becomes difficult to convince some non-professional, who has not felt the pinch of the lack of knowledge and the consequent need to use a large factor-of-ignorance in the design of hydraulic structures, of the necessity for research. The Government of Pakistan have already established a National Council of Research in the field of Irrigation, Flood and Drainage. It is hoped that liberal funds will be available with this council for financing the applied and basic research programs in hydraulics. The control of these finances, however, should not rest with the Finance Department, for two reasons that may be discussed here. For pursuing an effective research program, it is essential that the flow of funds for a project be continuous. It has been found that continuous, though limited, allocation are more fruitful than sporadic and uncertain grants. The past experience of the Institute shows that the Finance Department has a strong aptitude for arbitrarily cutting and reducing the grants of research projects. Secondly, once the allocations have been made, the financial control should entirely rest with the head of the Institute. It has happened on many occasions in the past, that when allocations for a proposed study were received, the requisite staff was not sanctioned and *vice versa*. Such situations not only thwart the research program but also demoralise the Institute. It is viable to delegate the function of allocating funds for the proposed studies to a Provincial Council, who can utilise the funds obtained from the National Council in the context of overall research program drawn by them.

Levy on other Agencies. Perhaps the funds made available by the National Council and the Provincial Government will not be adequate to boost up the research activity to the requisite tempo. These funds can be supplemented from other sources. The agencies benefiting from the work of the Institute can be made to pay direct grants to the Institute for carrying out research in their fields of interest. This levy can be a fixed percentage of their developmental and maintenance budgets in addition to the direct cost of the specific studies executed for them or as a *pro rata* charge

on the cost of work directly done for them. Either of these methods can be equally effective. This method of financing the research is amply justified, because the money thus spent on the basic and applied research will ultimately benefit these agencies by providing more generalised solutions which can obviate many of their specific studies and by improving the standards of research in the country. The funds thus obtained should be considered direct revenue of the Institute and controlled by the Provincial Council.

There are some other problems, which are minor as compared to the requirement of Manpower, Research Programs and Financing. These are problems of better library and bibliographical facilities and improved means of dissemination of technical knowledge. These problems are important in themselves and should be tackled by the proposed Council.

VI. PROVINCIAL RESEARCH COUNCIL

In the discussion of the problems facing the hydraulic research in West Pakistan, a high powered Council, for controlling the research activity in the field of land and water resources, has been proposed. A National Research Council for this field has already been established. It, therefore, seems necessary to enlarge on the constitution, scope and function of the proposed Provincial Council and its position *vis-a-vis* the National Council.

(*i*) Constitution of the Council

The Provincial Council should be headed by no less than the administrative head of the Irrigation and Power Department, because ultimately all the problems pertaining to hydraulic research fall under the purview of this department. Members of the committee should be drawn from the Irrigation Research Institute, Irrigation Department, West Pakistan Wapda, Land and Water Development Board, Agricultural Development Corporation, West Pakistan University of Engineering and Technology, West Pakistan Engineering Congress, Highways, Railway and the Finance Departments.

The inclusion of members from the technical agencies is necessary to represent their view-points both in the finalisation of research priorities and in the review of research programs pertaining to their interests. The Engineering University has to be represented, for bringing about a collaboration in the drawing up of curricula and the research needs, as well as in the apportioning of research program between the Institute and the University. The Finance Department has to be represented, for providing help in enforcing the necessary financial control, as the funds of the committee are not proposed to be routed through the Finance Department.

(*ii*) Scope and Functions of the Council

The scope of the Provincial Research Council should be to organise, control and promote the research in the land and water sector in West Pakistan. Its functions should be as follows :—

(1) To survey the needs of research in land and water sector in West Pakistan.
(2) To procure and administer funds from the National Council and Provincial Agencies engaged in the development and maintenance activities involving land and water.
(3) To draw up priorities of research needs in its sector.
(4) To sanction individual research programs, review their progress and evaluate them from time to time.
(5) To collaborate with the West Pakistan Engineering University and other engineering colleges in apportioning the basic and applied research program between the University and the Institute.
(6) To sanction cadre strengths for the research and auxiliary staff.
(7) To represent the provincial research interest in the National Council.
(8) To commission plans for improvements of manpower, research standards, research facilities and dissemination of knowledge.
(9) To guide the recruitment and promotions of the research staff.

(*iii*) Provincial Council *vis-a-vis* the National Council

The present charter of the National Irrigation, Drainage and Flood Control Research Council provides for organising, coordinating and promoting research in the various fields of Hydraulics, Irrigation, Reclamation, Tubewells and Flood Control. It further provides for making grants-in-aid to universities and other research institutes for specific schemes. The National Council is an autonomous body, with its membership covering a wide range of the sectors engaged in or interested in the research in these fields. It is proposed to obtain funds for its activities from the Government, Local Bodies, Patent Rights, Loans and Foreign Aid which will be utilised under a financial system to be drawn up by the Council. The Council is chartered to set up a national research institute in its field of activity and to establish a museum and a library among other things.

The existing structure of the National Council, however, does not provide for the establishment of Provincial Research bodies. There are certain handicaps involved in divorcing the provinces from organising their own research activity. The problems of the two provinces of Pakistan are

dissimilar in many respects. Their geomorphology, climate and hydrological features are different and so are their research needs. It would, therefore, seem more practicable to maintain the existing decentralised organisation of research in the Provinces. The National Institute of Research, even if set up, should not be developed at the cost of the provincial Institutes. The main tasks of the National Council can thus be : to promote research in the Land and Water sector, by arranging funds from the Governmental and foreign sources and apportioning them between the provinces ; to provide a joint forum for the research programs carried out at provincial level, thereby ensuring that the programs are in conformity with the national needs and that wasteful duplicity is avoided. It can also act as a clearing house for information available at the national and international levels, and it can advise the provinces about improved methods of dissemination of pertinent technical information etc. But, the detailed control of the utilisation of funds and execution of research programs should be left as a responsibility of the proposed Provincial Councils.

The relative position of the National and the Provincial Councils regarding finances can thus be envisaged. Of planning, the detailed programs of research need to be prepared by the latter and to be approved by the former only inasmuch as they can be financed by it. The Provincial Councils should be free to arrange their additional funds from sources other than the National and Foreign Governments.

In the arrangement outlined above, the charter of the National Council can be curtailed both in its scope and detailed functions. Its membership can similarly be reduced to the representation of the two Provincial Councils, the Central Government and public representatives from the two wings. A representative of the Auditor-General may also be included to advise on and help in delineating the financial procedures.

It is hoped that the organisation of research on the aforementioned lines will provide a vigorous impetus to the present pace. The suggestions made regarding matters of manpower, programming and financing, if implemented, can go a long way in producing centres of research which will be competent enough to solve all the national problems in the land and water sectors and will also be capable of widening the horizons of human knowledge in this vital field.

VII. CONCLUSION

The present and future prosperity of West Pakistan depends on the successful maintenance of its existing irrigation system and on an increasing exploitation of its land and water resources. A successful irrigation system needs, among other things, adequate diversion of water supplies and their

efficient conveyance. The gaps in the scientific knowledge, about the laws of hydraulic—especially the hydraulics of alluvial streams, call for an ever-growing research effort in this field. The present status of hydraulic research in West Pakistan is modest and needs considerable expansion in the basic and applied fields.

The essential component of any research program is the research worker. To accelerate the research activity in West Pakistan, prospects in this field have to be improved to attract suitable talent. In view of our limited economic and manpower resources, efforts in research can be made fruitful only if a systematic program based on the considerations of research needs and priorities is pursued. The financing of research has always been a vexing problem. This can be solved by levying charges on the agencies utilising the results of hydraulic research.

The research needs of the two provinces of Pakistan are different and as such it is necessary to develop the hydraulic research in both the wings independently, with a general coordinating role vested in the newly created National Research Council. Within the provinces, Research Councils need to be set up on the lines of the existing National Council to boost up the research in hydraulics.

REFERENCES

(1) Ahmed, Mushtaq, "Engineering Research". Section on Irrigation "Hundred years of P.W.D.". Publication of West Pakistan Engineering Congress, Lahore, October, 1963.

(2) Colyer, Cecil, A., "Research and Investigation Section for the Public Works Department". Paper Number 20, Proceedings of Punjab Engineering Congress, Lahore, 1915.

(3) Auger, Pierre, "Current Trends in Scientific Research" UNESCO, Paris, 1961.

(4) Ahmed, Mushtaq, "Some Measures to Promote Scientific Education and Research for National Development" Engineering News, Lahore, Vol. X, No. 4, December, 1964.

(5) Mason, Martin A., "Our Professional Responsibility-Development of New Knowledge". Civil Engineering, New York, Vol. 28, No. 6, June, 1958.

TABLE I

Growth of Work-load and Output in the Hydraulic Wing I.R.I. since Independence

Year	Research Personnel			Model studies in progress			No. of Technical reports issued	Cumulative No. of Technical reports.	No. of Research Personnel/ Model studies in progress		
	Gazetted	Non-gazetted	Total	Specific	Applied and Basic	Total			Total No. of Research Personnel	Total No. of studies	Ratio
1	2	3	4	5	6	7	8	9	10	11	12
1947 ..	*	*	*	*	*	*	..	..	..	..	..
1948 ..	3	19	22	*	*	*	7	7	*	*	*
1949 ..	3	19	22	6	0	6	15	22	22	6	3.67
1950 ..	3	19	22	*	*	*	12	34	*	*	*
1951 ..	3	19	22	*	*	*	11	45	*	*	*
1952 ..	3	19	22	12*	0	12	15	60	22	12	1.38
1953 ..	3	19	22	14	0	14	25	85	22	14	1.57
1954 ..	3	17	20	13	0	13	19	114	20	13	1.54
1955 ..	3	17	20	15	0	15	27	141	20	15	1.33
1956 ..	3	17	20	*	*	*	19	160	*	*	*
1957 ..	3	19	22	15	0	15	18	178	22	15	1.47
1958 ..	3	19	22	*	*	*	31	209	*	*	*
1959 ..	4	19	23	29	4	33	43	252	23	33	0.70
1960 ..	5	19	24	*	*	*	53	304	*	*	*
1961 ..	6	19	25	45	1	46	43	347	25	46	0.54
1962 ..	19	17	36	70	0	70	40	387	36	70	0.52
1963 ..	26	17	43	61	3	64	39	425	43	64	0.67
1964 ..	34	8	42	84	3	87	45	468	42	87	0.48
1965 ..	35	9	44	77	5	82	30	498	44	82	0.54

* Data not available.

1. Gazetted personnel include officers from Assistant Research Officer to Principal Research Officer's level.
2. Non-gazetted personnel include Senior and Junior Research Assistants. Supporting staff like Observers, Laboratory attendants, etc. have been excluded.

TABLE II

Component of Indus Basin Research in the Hydraulic Wing I R.I.

Year	Research Personnel						Total No. of Specific Model Studies		No. of Research Personnel/model studies		No. of Technical Reports issued	
	Gazetted		Non-Gazetted		Total							
	All	IBP	All	IBP	All	IBP	All	IBP	All	IBP	All	IBP
1960 ..	5	0	19	0	24	0	*	*	*	..	53	0
1961 ..	6	1	19	3	25	4	45	11	0.54	0.36	43	21
1962 ..	19	12	17	0	26	12	70	51	0.52	0.24	40	25
1963 ..	26	21	17	0	43	21	61	52	0.67	0.40	39	28
1964 ..	34	22	8	0	42	22	84	55	0.48	0.40	45	22
1965 ..	35	23	9	0	44	23	77	51	0.54	0.45	30	16

*Data not available.

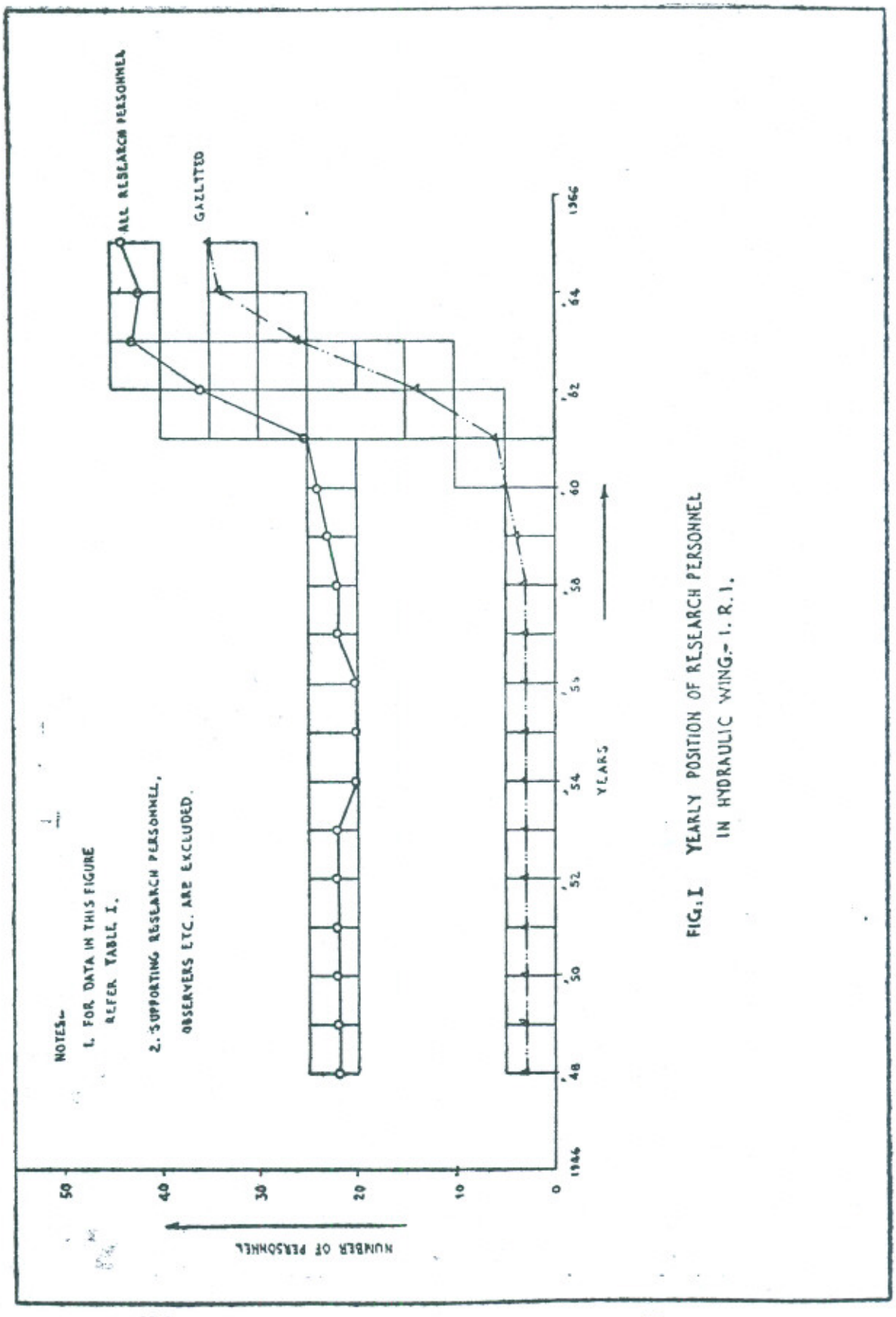


FIG. I YEARLY POSITION OF RESEARCH PERSONNEL IN HYDRAULIC WING.- I. R. I.

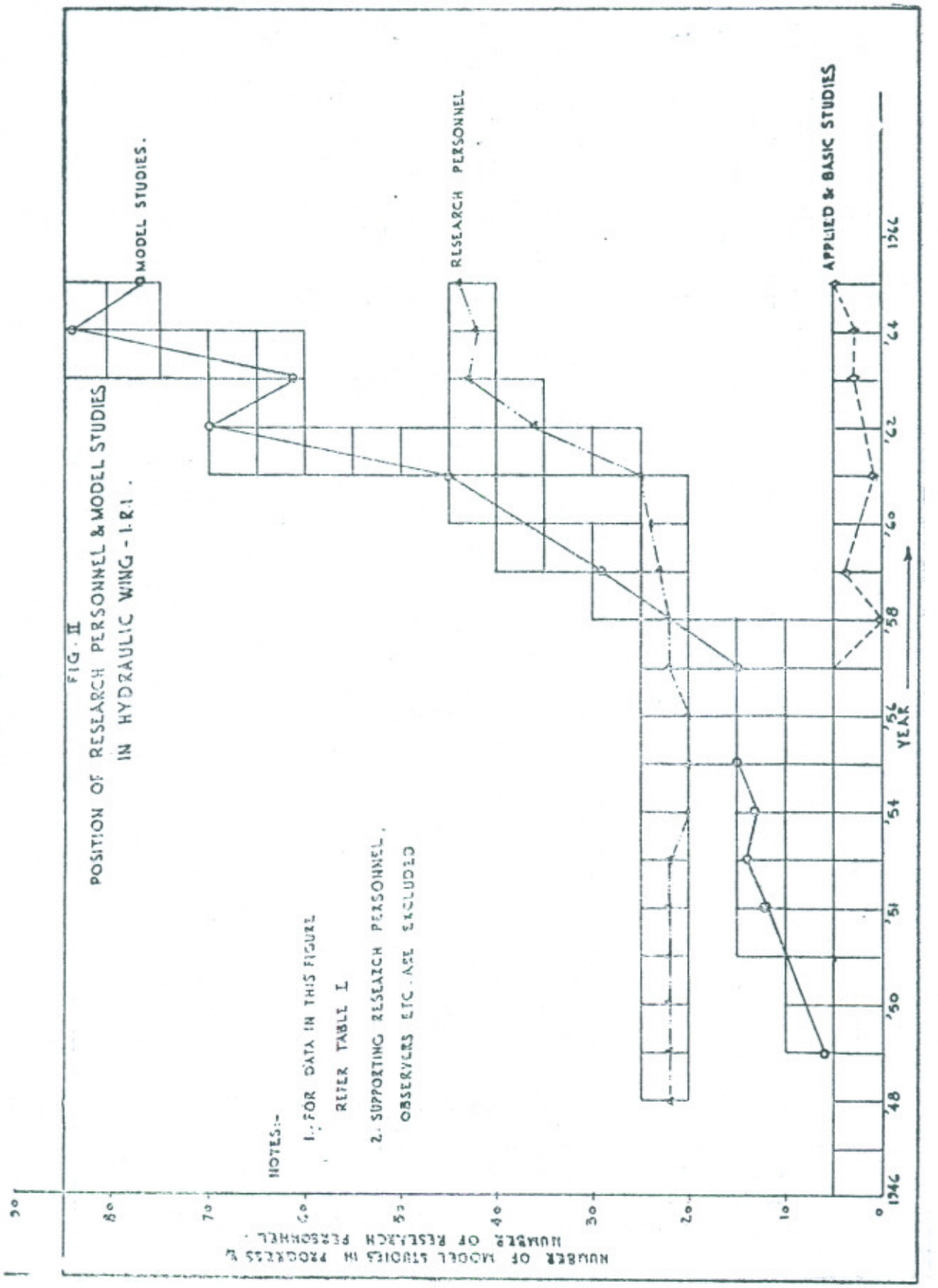


FIG. II
POSITION OF RESEARCH PERSONNEL & MODEL STUDIES
IN HYDRAULIC WING - I.R.I.

NOTES:-
1. FOR DATA IN THIS FIGURE
REFER TABLE I
2. SUPPORTING RESEARCH PERSONNEL,
OBSERVERS ETC. ARE EXCLUDED

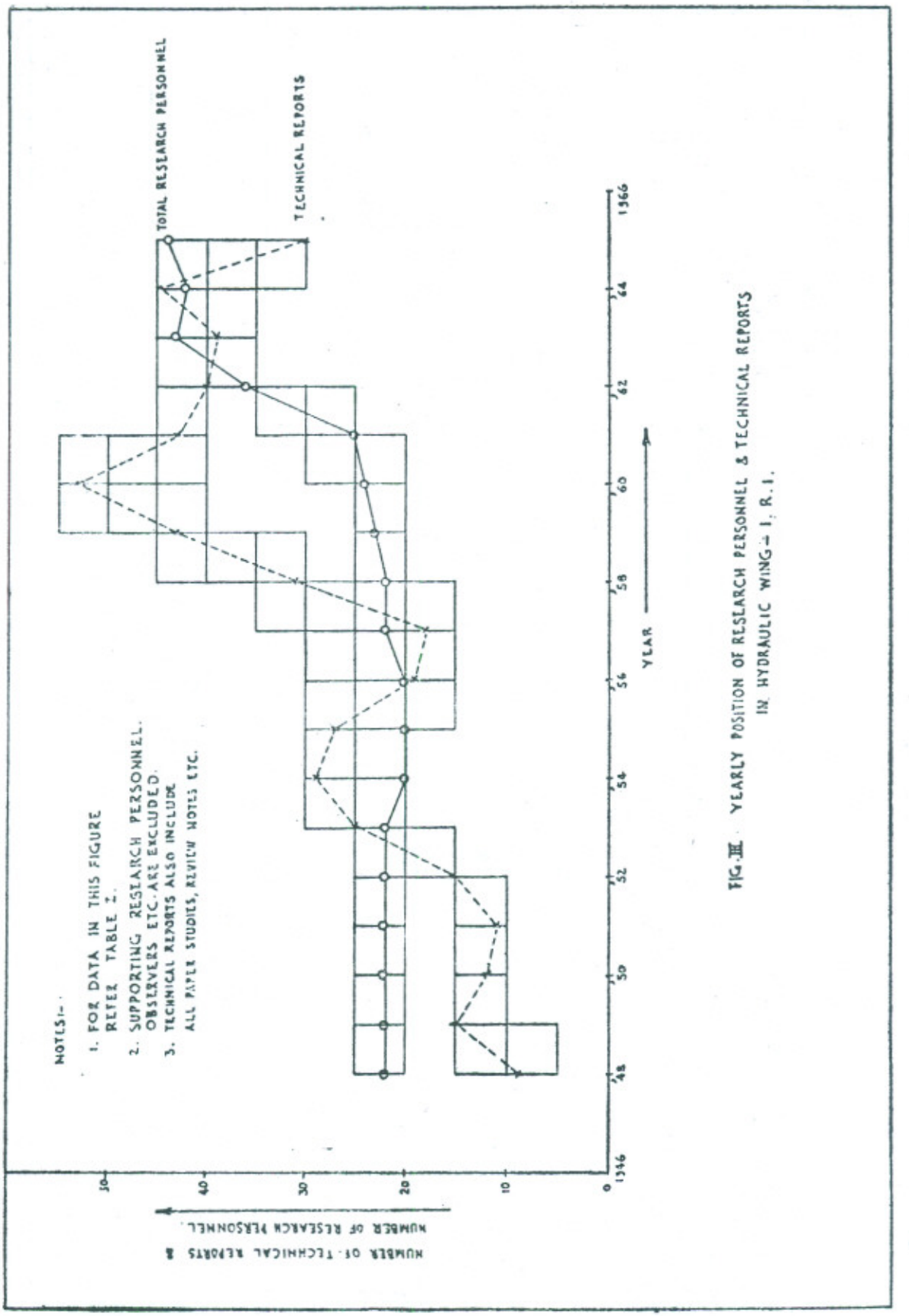


FIG. III YEARLY POSITION OF RESEARCH PERSONNEL & TECHNICAL REPORTS IN HYDRAULIC WING - I, R.I.

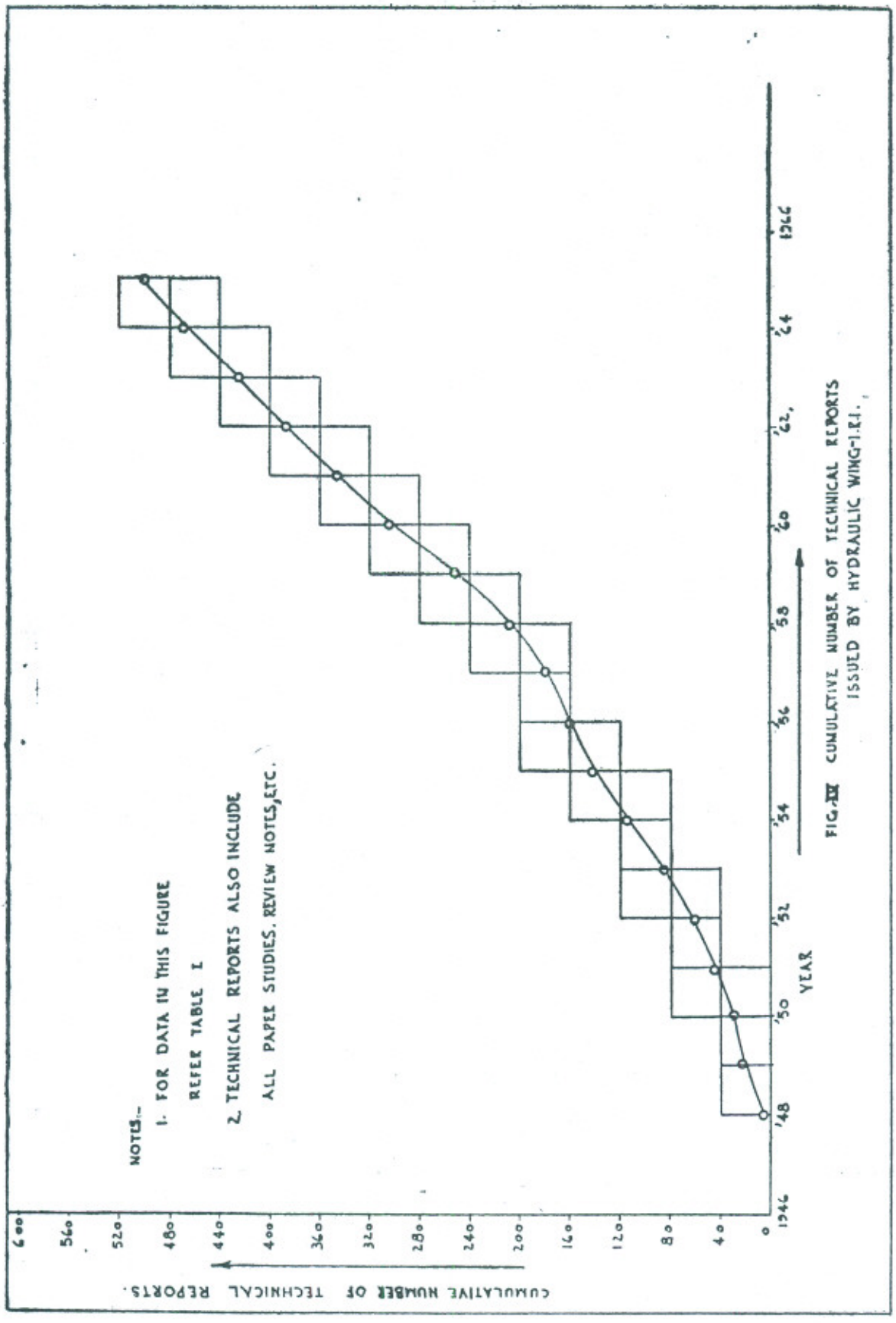
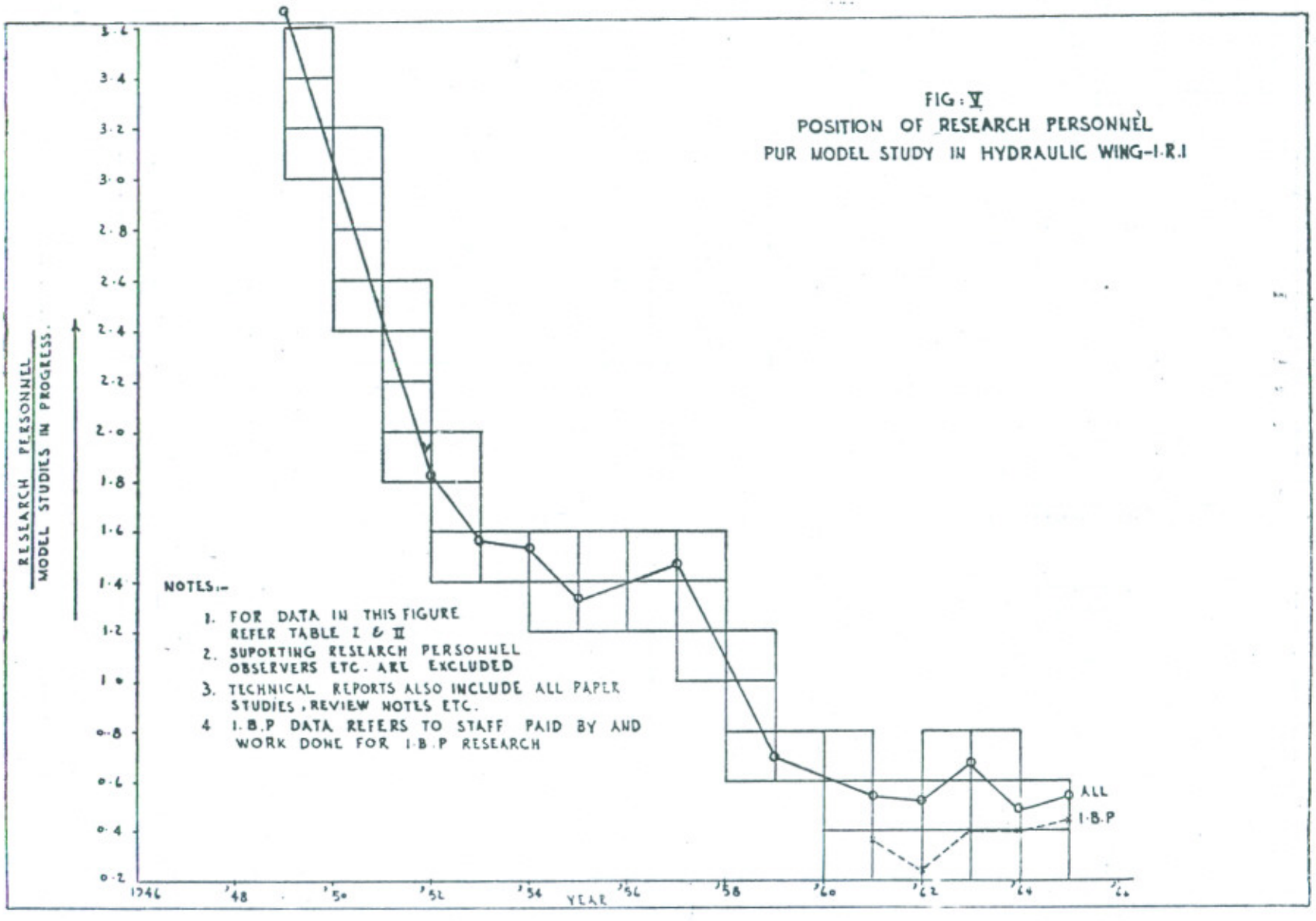


FIG-XII CUMULATIVE NUMBER OF TECHNICAL REPORTS ISSUED BY HYDRAULIC WING-I.R.I.


FIG : V
POSITION OF RESEARCH PERSONNEL
PUR MODEL STUDY IN HYDRAULIC WING-I.R.I
RESEARCH PERSONNEL
MODEL STUDIES IN PROGRESS.
3·6
3·4
3·2
3·0
2·8
2·6
2·4
2·2
2·0
1·8
1·6
1·4
1·2
1·0
0·8
0·6
0·4
0·2
1946
'48
'50
'52
'54
'56
'58
'60
'62
'64
'66
YEAR
NOTES:-
1. FOR DATA IN THIS FIGURE REFER TABLE I & II
2. SUPORTING RESEARCH PERSONNEL OBSERVERS ETC. ARE EXCLUDED
3. TECHNICAL REPORTS ALSO INCLUDE ALL PAPER STUDIES, REVIEW NOTES ETC.
4 I.B.P DATA REFERS TO STAFF PAID BY AND WORK DONE FOR I.B.P RESEARCH
ALL
I.B.P

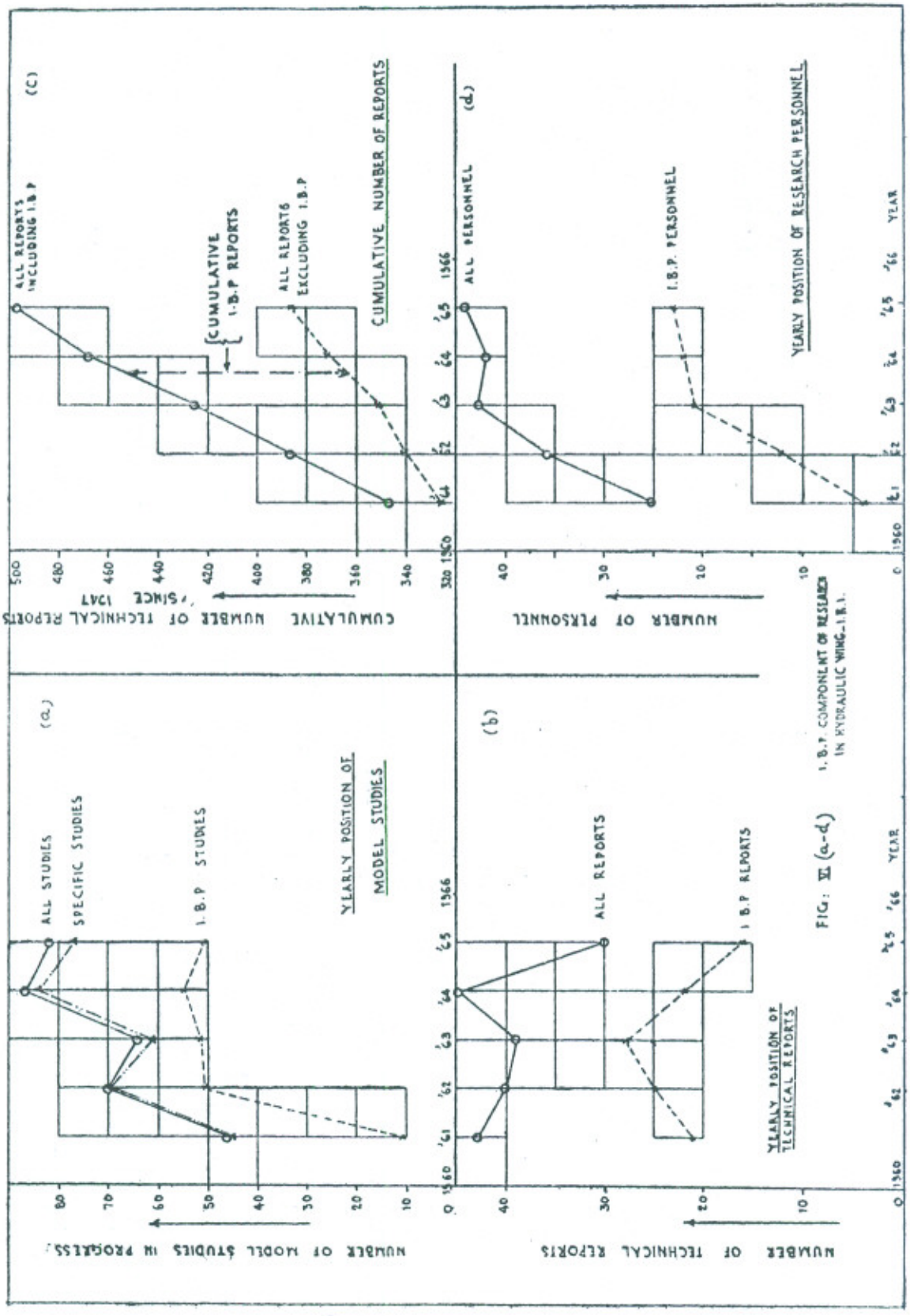


FIG: VI (a-d) I.B.P. COMPONENT OF RESEARCH IN HYDRAULIC WING - I.R.I.