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THE ANCHICAYA HYDRO PROJECT IN COLOMBIA
DESIGN, CONSTRUCTION AND SEDIMENTATION PROBLEMS

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PRELUDE

Fifty years of varied engineering and construction experience lead me to express several ideas worth mentioning since they were further confirmed by our many problems on the Anchicaya hydro project in Colombia. The first is my firm belief that careful and complete preliminary reconnaissance, including all important factors is the most vital part of any engineering project.This requires comprehension, experience, and vision, almost inspiration in fact, a quality acquired by few persons, whereas the later design work becomes more of a routine which can be performed by various specialists with less imagination. Nothing is more discouraging than to arrive on a project at a later stage and find that the preliminary project was defective, unsuitable, or with hidden or unmentioned factors which render the project more costly, less effective, or even seriously questionable when it is already too late to make desirable changes.

The second, is that engineering and construction literature and reports usually are perfectly legitimate success stories, whereas I sincerely believe that quite often more can be learned from mention of alternate plans, or changes, and of errors, failures or near failures, and types of "skeletons in the closet", if these are properly described, explained, and evaluated. Such major disasters as the failure of the Quebec bridge, the "galloping gertie" Tacoma bridge, and the Viant dam disaster in Italy were quite well publicized and of great benefit to the engineering profession, but I know that many successful projects have "hidden skeletons" about which nothing will ever be made public unless disaster strikes.

Lastly, I have been appalled by the almost complete lack of appreciation of the biological and ecological features now confronting the modern world. We have been rapidly spoiling our physical environment on this earth by man-made changes without realizing or understanding the long time effect of such alterations.

We have destroyed much of our forests and ground cover thereby increasing erosion, sedimentation of streams and reservoirs, increasing floods and probably even causing climatic changes. This is apparently one of the most serious and widespread of mans damages to nature. Populations have disappeared because of the destruction of forests. We have contaminated our streams with detergents, manufacturing and process wastes, including sewage in general. Soon the global water supply will be insufficient for the rapidly increasing population and manufacturing demands. We have contaminated and chemically altered the air we breathe with smog, largely because of use of fossil fuels, the burning of waste, and above all, the automobile, and lastly, by nuclear explosions. In our efforts to control insect and other pests we have disturbed the natural biological balance previously existing, caused greater resistance to pesticides and created new problems by damaging and in some cases destroying fish, bird, and animal life. We have contaminated air and soil with fall-out from nuclear explosions, with as yet unknown possible damage or effect on humanity. We live in a world with a high noise level, already known to be detrimental to hearing, and also are exposed to continuous bombardment by radio waves of various frequencies and power which may possibly have some "long time" influence on humans.

This impressive but partial list clearly indicates that modern technology has largely ignored the biological and ecological aspect of major development programs here and abroad. The conditions have now reached a critical stage and an increasing "awareness" of the problems must be stimulated if humanity, now under the scourge of a "population explosion", is to survive.

Referring specifically now to the Anchicaya project, several severe defects in the original planning can be briefly noted. The original reconnaissance possibly was at fault in not noting, mentioning, or using what appears to be a much superior damsite in a narrow gorge about 800 meters downstream of the present power plant (see Anchicaya area map), where a dam of over 150 meters height would have been possible. For some unknown reason this area was blocked out of the original topographic maps. The dam originally proposed at the present location was a thin arch, not suitable for the site, and the first 12000 cubic meters of concrete placed under the original plan was poorly constructed and partly on poor rock. The major error was that neither the originators of the project nor the later Consultanting Engineers who reviewed the project made any reference whatsoever to the sediment and debris problems or to the future deforestation already under way. Moreover, due to failure to note these future sedimentation problems, the outlet works proposed were completely unsuitable to handle the sediment load or the large quantity of debris, tree trunks, and uprooted vegetation carried by the Anchicaya river. Luckily, I was able to secure the modification of most of the objectionable features during the final design and construction of the project after joining the Anchicaya organization in April 1951 as Technical Advisor.

THE ANCHICAYA HYDROELECTRIC DEVELOPMENT

The following several pages will cover briefly the major features of the Anchicaya power development, and the various major problems encountered and changes made in the final construction period to make the completed plant more suitable for actual existing conditions.

The Anchicaya power plant, dam, and reservoir are all located in the steep walled canyon of the Anchicaya river in the southwestern portion of the Republic of Colombia, on the Pacific slope of the western range of the Andes mountains. The terrestrial location is about 3° 30 'N latitude and 77° W longitude. The power plant is inland about 30 kilometers from the Pacific ocean and 37 kilometers S 33° E from the Pacific port of Buenaventura. By the tortuous Simon Bolivar highway the plant is 50 kilometers southeastward from Buenaventura, and 90 kilometers northwestward from Cali. The very difficult Anchicaya section of this generally narrow gravel coated highway was not yet built when the first surveys were started for the project.

Cali, the principal load center for Anchicaya power is a very rapidly growing city, at elevation 1000 meters, situated in the Cauca valley adjacent to the eastern foothills of the western range of the Andes. Cali has an agreeable climate with fairly high humidity and had only 100,000 population in 1938, increasing to 250,000 by 1951, and reportedly reached 700,000 by 1967. The vicinity map attached shows the locations mentioned. The estimated 750 to 800 square kilometer drainage area of the Anchicaya watershed is roughly indicated on the map but it should be noted that this map is approximate only, since exact maps of the jungle area west of the

Andes do not exist. The Anchicaya generating station is connected to 2 substations in Cali, and to the later constructed steam plant at Yumbo by a double circuit 120 Kv line on steel towers, and finally, by a single circuit on double circuit towers to Buenaventura.

The Anchicaya plant was originally designed for 6 units of 12000 Kw and the first excavation work was started in 1944. By 1948 much of the equipment for the first two units had been ordered and part was already on the job, but lack of funds and a general feeling that the project should be revised, coupled with a fear that the thin arch dam design was questionable after the St. Francis dam failure in southern California, all combined to cause suspension of the work. Also, it was clearly evident that outside financing was necessary, thus a review of the project by competent engineers was a requisite for any I B R D financing. Following a review of the project by a U.S. firm who made quite a few major changes in the proposal design and definitely recommended changing to a gravity arch dam, financing was arranged, construction bids were advertised, and late in 1950 a design and construction contract was awarded to a Danish-Colombian firm, with work getting under way early in 1951. Except for fair success on the power house, this firm made very poor progress and accomplished very little on the dam, made numerous costly errors of judgment and the contract was finally canceled. After this, the contract was split up, the dam going to a French firm, the tunnel to one Colombian firm and the power house to another. Much of the work of completion, installation of equipment, penstocks, gate chamber, and valves for the first 2 units was handled by Anchicaya personnel directed by the writer.

The Consultants retained the 6 unit plan for the power house, and the new design and construction contract was for a 4 unit building with 2 units installed. Due to slow and unsatisfactory progress, the contract was revised to cover a two unit building with 2 units installed.

This decision permitted a reconsideration of the future units and as a result a design was perfected for 2 new units of 20000 Kw using only a little more plant length than originally intended for 4 units of the original plan. This revised plan enabled us to avoid cutting into a steep and known unstable hillside for an extension to 6 units, and decreased the total capacity to 64,000 Kw as against the oversize original plan of 72,000 Kw, and thus was a somewhat more economical solution. However, this plan created an almost impossible demand to immediately excavate for the new extension, complete the turbine base, and install front wall with portions of the draft tubes and necessary gates to keep the unit 3-4 area dry after demolishing the downstream coffer dam to permit operation of units 1 and 2. Luckily, despite floods and other difficulties the new partial construction was completed to above high water on schedule, and the power plant was placed in operation in June 1955, and the surge chamber, badly delayed by an enormous slide (see next paragraph), was placed in operation a month later. It is interesting to note that the top of the rock cut at the base of the unstable hillside previously mentioned moved about 2 inches into the excavation before concrete was placed. The longer excavation required by a 6 unit plant could possibly have caused collapse of the entire hillside causing a severe disaster. Numerous landslides in the construction areas at Anchicaya were one of the greatest hazards and caused quite a few deaths. It is almost unbelievable that a bronze plaque at the entrance to the powerhouse is dedicated to the 66 persons listed thereon who met death in connection with the job. Most of these deaths occurred during the earlier construction period, and I can say with sincere gratitude that no person in my direct employ ever had to be listed on the plaque.

The surge chamber was our most dangerous construction problem, and also the most controversial design feature, since it involved the final diameter of the conduction tunnel already excavated, an original location on an already partly excavated bench in an unstable steep mountain-side of finely laminated blue schist, almost directly over a smaller lower bench at the lower end of the conduction tunnel where a large chamber for a 3 prong wye remained to be excavated. The Consultants were undoubtedly disturbed about the security of the existing excavations and recommended a 15 meter diameter differential type surge chamber for 4 units, and a second smaller tunnel and surge chamber for the last 2 units originally proposed. They also recommended careful excavation, and removal of dangerous slopes. After viewing the site I was convinced that conditions were too critical to continue even the modified plan, but despite my objections the designer-contractor perfected the design of a 22 meter diameter surge chamber in the original site and the 1/2" plate steel lining required was purchased and delivered to the job. (This lining was later sold at a profit). Before this contract was canceled the contractor avoided work on the wye and the surge chamber, but had enlarged the conduction tunnel to 6.3 meters diameter which had started a rock fall directly under the proposed surge chamber platform. This rock fall, which continued to enlarge, ultimately required 1000 cubic meters of concrete and rock backfill placed by Anchicaya employees. I had previously reported a near vertical fault break nearly exactly on the center of the proposed surge chamber where this rock fall occurred. Also, I had discovered a partially open crack in the hillside some 70 meters above the surge chamber site and had filled the crack with tamped backfill to prevent the entry of surface water. All of these items contributed to the lack of confidence in the stability of the proposed surge chamber, and when the construction contract was canceled, a re-design was considered necessary. Several different proposals were made by the various Consultants. I proposed a very unusual differential type surge chamber, entirely underground, using the vertical riser 6 meters in diameter, a top connecting tunnel to a vertical fully reinforced domed circular chamber 22 meters high and 15 meters inside diameter at the top, and 16 meters diameter in the lower portion, a spillway tunnel on the far side, and a small tunnel connecting the bottom of the cylindrical chamber and the riser. The cylindrical chamber was offset 32 meters on centers from the riser. My solution, which was finally used, despite opinions by consultants that it would permit operation only up to 80 percent of capacity of a single or all units, also contained provision for a second and smaller chamber if ever required. Actually, whether by luck or a happy combination of dimensions, this surge chamber has given complete satisfaction at all loads up to over 10 percent overload of any or all units. The oscillation of water level under all operating and fault conditions has been extremely small, and at no time has the water passed over the top of the riser.

The construction of this surge chamber, part by contract but mostly by Anchicaya personnel forms an "Odyssey" too long to include herein. Numerous small slides resulted, and one major slide of about 25,000 cubic meters on November 4, 1954 during a torrential rain buried forever the entire working area on the original surge chamber site, covering office, concrete mixer, cement, aggregate, reinforcing steel and miscellaneous equipment. This disaster, luckily causing no injury to personnel who were all inside the mountain due to the unusually heavy rain, happening only 8 months before the final operating date, added force to the continued newspaper clamor in Cali of "Anchicaya Nunca", or in english "Anchicaya-Never".

The contractor delayed a month before resuming work by starting excavation of a small heavily supported tunnel through the slide, but could not be persuaded to start excavating a ring around the base and constructing the cylinder wall upward while working downward from the top. Thus, Anchicaya crews worked upward in the main chamber while completing the lower portion of the riser and the bottom connecting tunnel. The upward advance was later stopped as the two levels of work approached, the outer wall was completed, the center rock mass was removed, the floor of the chamber was completed, the plant shut down one day to remove the wall placed in the lower passage to permit the previous months operation of the plant with only the riser as surge chamber, then the tunnel was refilled, and has never been dewatered since, despite the later addition of units 3 and four.

THE ANCHICAYA DAM

The proposed gravity arch dam followed more closely the consultants recommendations, except for an entirely new concept of combined outlet tower attached to the dam with a higher conduction outlet in the upper portion and a sluiceway outlet below. The final design of the dam was handicapped by the existence of the 12000 cubic meter block of concrete on the right bank placed in a somewhat haphazard manner as part of the proposed thin arch dam in the original construction period as noted in an earlier paragraph herein. Excavation for the recommended gravity arch dam quickly revealed decomposed diorite under the downstream toe of the original construction, with much honeycomb in the original concrete. Since it was considered inadvisable to destroy this block, the Consultants provided designs and made certain recommendations as to suitable methods of grouting, scaling, and other features to incorporate this block within the new structure. One of the major defects was that the existing blocks were placed on rock with a heavy downstream slope radially. The left abutment also had this defect, which was somewhat bettered in the final construction, but had better rock than the right abutment. As a final resort the dam in general was moved slightly upstream, with the major move on the right abutment, and a large tunnel was excavated through and under the old block to lock the new construction completely around the lower portions of the old block from which much honeycomb and soft rock was removed.

There was no core drilling performed on the damsite during the original construction, thus nothing definite was known as to the depth or suitability of the river channel. Core drilling at a later date sloping downward from the river edges at about 45° revealed sound quartz-diorite with few seams, at around 10 meters depth of water, and this was fully confirmed when the excavation was completed. This excellent foundation for the center blocks added much stability to the final structure, and a large number of large 1" and 1-1/4" reinforcement bars grouted in the rock on the sloping abutments added additional resistance against possible uplift and sliding.

The dam is of the overflow type with "ski-jump" features on the downstream slope to prevent downstream scour near the base of the dam. The central portions of the spillway have a total length of 111.0 meters at elevation 194.4 meters and 15 meters length of additional spillway adjacent to each abutment is at 195.2 meters. The abutments are at elevation 201, with walls one meter higher. The total dam length is 206.5 meters, and the maximum height of dam from base rock to spillway crest is 53 meters. The calculated overflow capacity is 5700 cubic meters per second. One gallery leads from the right abutment to the outlet tower, the central gallery is further downward and passes horizontally through the dam rising to the left abutment. The lower gallery, connects with the central gallery on each side and contains the mechanism for the two 5'x6' hydraulic operated sluice gates. The dam was constructed in blocks normally 15 meters wide at the upstream end, with 1.5 meter raises and moveable forms usually set up two lifts high when assembled for placing, the bottom lift being on the previously placed concrete and acting as a base for the new lift form.

Concrete aggregates were to be obtained from a new quarry located a short distance from the Anchicaya camp. I considered the site impossible.

The contractor spent about $30,000 U.S in developing the site with practically no results, and the site was abandoned later. When the french company took over the construction of the dam, they opened a large quarry about 5 Km upstream with favorable operating possibilities but had to use some river gravel and also sand. All material had to be hauled to the primary crusher set up originally near the just, site mentioned, then be handled by a cableway to the secondary crusher located above the dam-site, then spilled into bins, from which it was transported to the mixing plant just above the dam. After mixing, the concrete was delivered by buckets from a cableway above the dam. These items generally worked satisfactorily but slippage of splices on the continuous cableway between primary and secondary crushers caused many delays, a problem never solved by the british suppliers. I still believe that this slippage, previously unknown elsewhere, was due to a rapid growth of algae common to the excessively humid tropics. Another strange "quirk" was that the cableway at the dam, completed and tested, fell during the first night, quite evidently due to a poor soldering job in the end clevis. Another previously unknown item was the fact that the crushed rock became quickly coated with a slightly greenish gray coating resembling paint which could not be washed off. Samples sent to the university in Medellin for testing gave no remedy except slightly longer mixing time to partly abrade the coating, and indicated that this coating could cause a decrease in strength of 10 to 15 percent in the concrete. It was presumed that the crusher dust from the diorite somehow combined to form the coating, but here again, no positive cause was identified. These items are mentioned since primarily produced by the effects of the hot, humid, tropical climate with excessive rainfall. The transmission line galvanized towers in the Anchicaya area also became quickly coated with a similar "paint", and the top surfaces of the porcelain insulators also. The skirts of the insulators rapidly accumulate algae and insect or wasp desposits, sometimes up to a centimeter in thickness. Use of silicone grease has ameliorated this condition somewhat but quickly creates a horrible appearance. Many other interesting features of the dam and the construction thereof could be mentioned but are not unusual enough to warrant inclusion herein.

THE ANCHICAYA DIVERSION TUNNEL AND BOTTOM OUTLET.

The Consultants recommended use of the already excavated diversion tunnel, with entry already provided with guides for use of a large car-wheel gate, which was also on the site, for a future bottom outlet equipped with a Howell-Bunger valve inside the dam. A completely useless wide spaced trash rack was contemplated. When I first saw the site in 1951 the diversion tunnel entrance was about 95 percent blocked with tree trunks up to near a meter in diameter, along with debris and boulders. This was positive proof of what would happen to any bottom outlet in short order with no means provided to remove or prevent the entry of large debris. No further consideration was given such plan, and in fact the debris was never removed from the entrance, and a permanent tunnel plug was later installed downstream of the obstruction. Since this old diversion tunnel entrance left no room for an upstream diversion dam, a new tunnel was branched off the old one and extended some 100 meters upstream, and a large gate was proposed by the Contractor for closure. Here again, slow and costly progress forced a new solution, a man-made slide to close the entrance. It so happens that the diversion tunnel was never completely opened. Despite my warning, the Contractor failed to protect the tunnel entrance by high enough dikes, and an early September flood swept into the tunnel, requiring a 3 month delay to divert the river from the tunnel, complete the removal of equipment and permit final re-diversion into the tunnel, and permit the construction of the upstream coffer dam.

The sealing of this diversion tunnel after construction of the dam, was effectively obtained by the provoked landslide on February 14, 1955. Unfortunately the contractor, very unwisely and without my knowledge, attempted to seal the lower end of the diversion tunnel by a similar landslide, which failed, and blocked entry to the tunnel to place the temporary upstream plug. Nearly a month passed, and work on the plug was barely started when a 500 M^3/sec. flood put a great depth of water over the slide sealing the upstream end of the tunnel, causing the "blow-out" of the seal.

This failure created a new and very serious problem since insufficient material remained on the slope above to reseal the tunnel by another provoked slide, and the flood season was rapidly approaching. The emergency was met by sealing the entrance of the tunnel about half way with a concrete beam extending down to water level, and a newly provoked slide on April 4, 1955, which nearly sealed the entrance and required an all day battle by some 75 men and a bulldozer to finally stop the dangerous infiltration. The plan was to start dropping concrete down an existing shaft the instant that tunnel flow stopped. Here again, the plan was delayed due to ineffective planning, and progress was slow. This safety plug should have been completed within 48 hours more or less, and was a great risk since the base was on the two or more meters of gravel left in the tunnel. Several days later, fearing a new flood, I found that the top of the concrete was still about 2 meters below the roof of the tunnel and ordered the immediate construction of a two foot thick concrete wall sealed to the roof. This was accomplished and about 12 hours later a new flood of 600 meters occurred raising the water level about 30 meters above the tunnel plug. Everyone feared that the fresh concrete in the thin wall, or the gravel under the plug would fail, but luck was with us this time and everything remained intact. This plug was then strengthened, then the final plug was placed in sections just below by removing the more than 2 meters of gravel in narrow strips, placing concrete, then repeating in successive strips until the gravel under the preliminary plug was entirely sealed off. After this, the full tunnel plug was completed in a normal manner. It should be noted that this sealing of the diversion tunnel was scheduled for March, normally the period of lowest flow of the year, but because of the difficulties mentioned, extended through April. Anchicaya flow records show that March and April 1955 had the highest flows ever recorded for these months, nearly twice normal. "Mother Nature" seemed to always show her resentment against Anchicaya and help promote the phrase "Anchicaya Nunca".

Since the proposed plan of the consultants to use the original diversion tunnel for a future bottom outlet had been completely abandoned, the next pages will describe the combined outlet tower.

Photograph

PARTLY COMPLETED ANCHICAYA DAM AND OUTLET TOWER AS OF JUNE 14, 1954

THE ANCHICAYA COMBINED OUTLET TOWER

The Consultants revised design for the conduction tunnel intake consisted of a large vertical shaft descending from a bench well above high water level and directly over the conduction tunnel, designed to house the car wheel gate, trashrack, stop logs, access to the tunnel, necessary ladders etc, with an above ground structure for operating equipment. The major defect in this plan was the long open end of the conduction tunnel with only a rudimentary grill with large openings with no provision whatsoever for removing large tree trunks and other large debris which could enter the tunnel. I proposed an exterior sloping trash rack structure built on the rock surface over the existing tunnel entrance, with grooves for trashrack units with small openings, and included grooves for massive concrete beams to be placed below the moveable trash racks as the sediment elevation continued to rise. This method would have provided perfect service for Anchicaya until the reservoir was practically filled with sediment and could readily have been supplemented later for full run-of-the-river operation. Unfortunately, the seriousness of the sedimentation and debris problems had not yet been recognized, and the Consultants consistently maintained that "there would be no sedimentation problem". Thus, since the designer-contractor also was unfavorable to such new design, the idea was abandoned. Then, since I had already considered and had mentioned a combined outlet tower attached to the dam as second choice, this idea was "pushed" and finally approved by all concerned. The location of the proposed structure was practically fixed by a firm rock bench on the right bank of the river and several meters above normal river level requiring relatively little additional excavation, while at the same time providing perfect coordination with block IX of the dam, and a correct angle so that the discharge of the proposed pair of 5' x 6' sluicegates would not hit the right bank below the dam.

The massive reinforced concrete outlet structure rises to an operating floor at El. 201 meters from a base at around 150 meters. The gate operating mechanisms are in separate structures above the floor with pits to store the car wheel gates below floor level. Gates are lowered by gravity in emergency, with normal lowering and raising ~~car wheel~~ by electric power. One gate serves the two sluicegates and is located on the dam proper, whereas the conduction tunnel gate and gate house is entirely on the outlet structure. The conduction tunnel is connected to the outlet tower by a massive circular reinforced concrete conduit supported on piers. The intake face of the tower, best shown on a drawing entitled "Sediment Profile Adjacent to Outlet Tower", has 3 equal vertical rows of trash racks, with sluiceway trashracks from elevation 154.5 m. to 165.0 m, then a sealed section, followed by the conduction trashracks from 169.0 m. to 184 m. The lower trashrack grooves are offset outward, to permit separate operation and raising when necessary, and a electrically operated trashrack rake can be placed in any one of the 3 bays on either top or bottom trashracks. Also provided is an electrically operated crane, suitable for use with a special beam to hook and lift trashrack sections, or to use a large gang hook for removing tree trunks which lodge against the trashracks.

The main object of this combined outlet tower was to maintain the area in front of the conduction tunnel intake free of sediment for the longest possible time by opening the sluicegates in times of heavy floods, and from time to time under normal conditions. The effectiveness of this method is very clearly shown by the funnel shaped depression existing around the intake tower even though the sediment deposit 30 meters upstream was already higher than the conduction tunnel intake for several years, and still rising. Only in 1967 was dredging started in the lower portion of the reservoir, and only in 1968 was dredging started adjacent to the tower, all of which will be described later herein.

The previous pages have provided a general description of the Anchicaya project and its major construction and design problems, much of which could be of value to those interested in international development which often presents very special problems not common in the highly advanced North American and European countries. The Anchicaya plant, despite the immense difficulties encountered in design and construction has been a highly successful plant with relatively low investment cost and a low power cost. As such, it has contributed greatly to the growth of Cali , and the proposed new Upper Anchicaya project to be mentioned later herein will greatly increase the available power at a low cost and further stimulate the growth of Cali and the surrounding region.

THE SEDIMENTATION OF ANCHICAYA RESERVOIR

The previous pages have repeatedly made reference to changes made in the design and construction of the Anchicaya hydro project because of an anticipated sediment and debris problem, completely ignored by the originators of the project, and the Consultants in their review of the project before financing was obtained from the IBRD.

The following pages will describe the conditions leading up to this problem, the efforts made to ameliorate the problems encountered, to present what is probably the most authentic record of sedimentation of a small reservoir that has ever been made, and finally, to present the latest ideas on what has to be done in the future to extend the life of the reservoir.

When the Anchicaya project was originally being studied and work initiated in 1944, the present Simon Bolivar highway which now passes the Anchicaya plant area was still under construction, and there were few settlers in this generally steep walled V canyon, and very little deforestation. Thus it is not too surprising that the originators of the project failed to realize that the major cuts of the highway on the very steep slopes would cause serious landslides and the influx of settlers would speed the destruction of the jungle cover, also increasing the landslides in short order, and thus cause greatly increased sedimentation in the river, and an enormous increase in the debris problem. However, these same originators of the project had in plain view the enormous "playas" of the Digua which already contained enough sand and gravel to fill the small reservoir proposed for the plant during one really .... ~~(continued on the following pages)~~ ....

major flood. It can only be concluded that the originators lacked vision and full comprehension of what would happen in the future.

The first apparent apprehension as to possible sedimentation apparently came shortly before the Consultants made their report when a major slide some 100 meters upstream of the damsite created a low dam causing pondage which very rapidly filled with sediment. The then manager wrote a letter to the Consultants noting the sedimentation and requesting information on possible sedimentation rates. The reply was roughly that tropical rivers carry little sediment and that there would be no sediment problem at Anchicaya.

After my arrival at Anchicaya in April 1951 I became alarmed by the visible evidence of the large gravel playas of the Digua river, and the large quantity of tree trunks and debris left high and dry after each flood, and was certain that both sediment and debris would cause major problems at Anchicaya, and my first report thereon was dated May 1951. The following are excerpts therefrom:

1. "Immediately upon starting work for Anchicaya, the silt problem in the proposed Anchicaya reservoir assumed major importance in my studies of the project and proposed outlet works, since familiarity with streams in the western U.S. made the extremely small reservoir appear hazardous to future successful operation of the proposed development."

"In considering the problem a letter was written to the Consultants suggesting consideration of the problem and possible alteration of the proposed intake, with the result that the previously expressed idea that "there was no silt problem in tropical rivers" was repeated. I do not agree with this concept and will discuss the problem from a purely conjectural basis since no actual facts regarding the Anchicaya are available."

2. "Records of other rivers are of major importance.

The Mississippi river, with very flat slopes over the major portion of its length, is estimated to carry 1500 parts per million of silt or .0015, or about 1/7 of one percent.

A minimum is the Illinois river shown with .00004 parts per million.

On the other hand, Southern California areas in 1938 showed quantities as follows:

60,000	cu.	yd.	per	sq.	mile	on	160	sq. mile	diamage area
70,000	"	"	"	"	"	"	50	sq. mile	diamage area
125,000	"	"	"	"	"	"	25	sq. mile	diamage area.

These last are extremely heavy erosion and transportation figures and would give on an area as large as Anchicáya (estimated as 750 sq. kilometers or 290 sq. miles) assuming 50000 cu. yd. per sq. mile, some 11,000.000 cubic meters or more than twice the sediment required to fill the reservoir level-full. Actually, coarse material will stop in the upper reaches of the reservoir and in part above normal water level, and moreover the chances of such storms and such heavy erosion are slight, but even one tenth of this amount, or 1,000.000 cu. meters would decrease the reservoir by 20%, with possibility of a storm of such size quite probable. At Obras Neusa, near Zipaquira, Colombia, a .35 to .70 cu. meter stream where 16 meters was the observed previous maximum, an abnormal 75 cubic meter per second flood moved about 200,000 cubic meters of boulders, cobbles and gravel out of a narrow canyon in about 48 hours, depositing the debris at the mouth of the canyon, swamping and wrecking a power plant. In the Mojave desert of California I witnessed the results of a 24 hour storm which stripped every vistage of vegetation from 15 miles of canyon, depositing a delta 1/3 mile long in Parker reservoir and carrying floating debris down to Parker dam which required many weeks of work with cranes and trucks to remove from the reservoir. I have thus witnessed both in Colombia and the U.S. erosion from single storms which under similar conditions would seriously endanger the Anchicaya project.

3. "Returning to the figures shown above, assume that the Anchicaya carries one tenth as much silt as the Mississippi or .00015. With an average flow of 90 cu. meters per second the annual volume carried by the Anchicaya is about 2,800,000,000 cubic meters, which at this factor would equal 420,000 cu. meters of sediment per year, or, with a reservoir capacity of 5,000,000 cu. meters a life of reservoir of 12 years. Assuming that only half of this amount would settle in the reservoir, the balance being carried over the spillway or through the turbines, would still leave a life of only 25 years."

4. "The above figures are highly hypothetical. Nothing is known of the actual silt content of the Anchicaya or the percentage of the actual content which is bed load. The bed load is of extremely great importance in heavy floods and will probably be the deciding factor in the life of the reservoir. A river like the Colorado, with about one percent silt content, would fill the reservoir in less than 100 days! The reported silt content in the Yellow river in China would fill the reservoir in less than 20 days if all sediment was deposited."

The sediment contents noted above were obtained from a table on page 131, Davis Handbook of Applied Hydraulics and other published data, consequently it appears completely impossible that competent engineers failed to realize the seriousness of the Anchicaya sediment problem. With the reservoir capacity of 5,081,000 cubic meters, and an average flow in the Anchicaya of 90 cubic meters per second (7.776,000 cubic meters per day) the reservoir would fill one and a half times daily, and even the extremely low figure of the Illinois river .00004 would produce 300 cubic meters per day of sediment, or about 110.000 cubic meters per year placing the life at 45 years. Having seen the Anchicaya river in flood, actually a tumultuous torrent on a grade of over 1.5 per cent, extremely muddy and carrying quantities of logs and debris, sometimes hearing the shock of large boulders in motion, would quickly convince anyone that the Anchicaya was not a sediment free stream. Moreover, in 1921 on the San Juan river in southern Utah, I witnessed a "mud flood" resembling a brick colored paint from which samples left standing overnight showed about 60 percent mud. During this flood, which lasted several hours, fish were swimming upstream gasping for air with bodies nearly half out of water. Millions of fish died and the stench of their decaying bodies was very bad for several days after the flood. The river slope was only about 5 feet per mile but the heavy mud laden water flowed very rapidly and actually "banked" on curves. Immense "sand waves" sometimes 10 feet in height continuously formed breaking upstream with a roar that could be heard for miles. During the flood the sandy bed of the river was apparently largely in motion, with the sand continually shifting. This spectacular performance by "Mother Nature" helped me picture what could happen at Anchicaya in a really major flood.

Shortly after my May 1951 report partly quoted above, I wrote a memorandum wherein I estimated a minimum reservoir life of about 7 years, a maximum of 25, and a probable average life of 25 years for the Anchicaya reservoir, and proposed various changes in the design of the outlet works and certain other features. This and other correspondence exchanged with the designers in Copenhagen finally resulted in convincing them that sedimentation would be a very serious problem and they finally sent a memorandum wherein they estimated the life of the reservoir as about 13 years, somewhat more critical than my estimates.

These various reports anticipating early loss of the reservoir were submitted to the Consultants, who replied in part in February 1952.

"We do not believe that the estimates as to the possible rate of annual accumulation of deposits in the reservoir are justified." Also: "We are of the opinion that the Anchicaya watershed is such that the deposits will not accumulate to a serious extent within the economic life of the plant."

It is extremely unfortunate that such highly erroneous opinions were ever expressed, and luckily such opinions did not prevent me from making many changes in design to better cope with the many sediment and debris problems I anticipated. Even at this early date I had already mentioned control of deforestation and construction of debris dams as partial answer to the still unsolved sedimentation problems.

Between late 1951 and April 1955 design and construction was the primary occupation of everybody concerned, and some important problems have been covered in the first part of this paper, and it is only after closure of the dam that factual sedimentation could be observed.

SEDIMENTATION RECORDING

Shortly before closure of the dam in April 1955, a sand bar had appeared on the inside of the first curve at the upper end of the reservoir. This was probably largely due to waste materials from the rock quarry a short distance upstream, but continued to build up rapidly after the closure of the dam and shutting down of the quarry. Shortly thereafter new sand and gravel bars appeared further downstream bringing the sediment deposition into full view. By the end of 1955 which was a year of heavy flow, it was clearly evident that the reservoir was filling rapidly and that controls, previously suggested, had to be established to measure the sediment input. Accordingly, surveys were started placing sounding section stations in suitable locations about 100 meters apart along the reservoir. These stations were numbered continuously starting with number 1 on the right abutment of the dam and number 2 on the left abutment, with odd numbers on the right bank and even on the left bank with the last upstream section numbered 55-56. These locations were plotted on the existing fairly accurate topographic maps made by the originators of the project. Cross sections of each sounding section were prepared using these original topographic maps since practically the entire section was under water or already covered by sediment. This series of cross sections was used as a basis for all future soundings, and for plotting each new sounding profile. A large tabulation was made showing the volume between each sounding section for 5 meter intervals vertically. All of this preliminary work took time, thus the first complete set of soundings was not made until December 1956, some 21 months after closure of the dam. Calculations revealed that the total sedimentation in this period was 1,188,000 cubic meters, or 23.4 percent of the reservoir volume. This record, for an average flow of 98.5 cubic meters per second, roughly 5 percent above normal at the time, clearly indicates what could have happened with an average flow of 123 cubic meters per second in 1949-50, in view of the fact that the increase in suspended load in most rivers varies at a rate somewhat greater than the square of the rate of discharge. Using this rate and 123 cubic meters flow, the sediment volume could have been 70 percent higher or over 2,000,000 cubic meters or 40 percent of the reservoir capacity in 20 months. This is purely theoretical, but perfectly illustrates the hazard that exists at Anchicaya. Needless to say, the actual loss of 23.4 percent of the reservoir in about 21 months caused surprise and fully justified my previous estimates of life of the reservoir. However, since there was much construction work in progress, the sediment problem was largely something for mañana, a Latin American custom.

The second sediment sounding of October 1957 was received with some relief, since the new deposit was only 167,000 cubic meters in a 10 month period, with a very low average flow of only 60.0 cubic meters per ~~flow.~~ second. However, much more interest in the sedimentation problem had been aroused in the intervening 10 months. Aerial exploration had been continued on the proposed Upper Anchicaya project, new aerial photographs had been made, and a stadia survey had been carried into the area, and a cost estimate prepared all indicating that an upstream development on the Anchicaya would ultimately be constructed and help decrease sedimentation in the reservoir. Sites on the Digua river for future debris dams had been investigated. All of these were of vital interest to the future of Anchicaya reservoir. Thus, my major report entitled "Methods for Preventing Rapid Sedimentation of Anchicaya Reservoir" was presented in November 1957, 8 single spaced pages, far too long to be included herein, but some excerpts and condensations are of importance.

Referring to the sedimentation records, "Such conditions indicate the necessity of whatever measures can be taken to retard the sedimentation rate and prolong the life of the reservoir."

Relative to sediment characteristics: "Sediment deposited in reservoirs can be divided into two classes:-first, the suspended sediment, normally only fine grained to microscopic which remains suspended in the flowing stream and slowly settles out as mud in relatively still water. This suspended sediment gives the water its muddy appearance, and settles out more or less uniformly over the entire still water portion of the reservoir. The second or bed load is that larger grained material which is rolled along the bed of the stream and is deposited in sand or gravel bars wherever the flow velocity is decreased, and is immediately deposited when still water is reached. Such material immediately starts forming sand bars in the upstream end of a reservoir, the steeply inclined front of which advances downstream as more material is deposited. This bed load is the most serious in a reservoir since it deposits in the active storage section, thus immediately decreasing the regulatory storage available."

"There is no fixed dividing line between these two classes, even in a single stream, since flood conditions with high velocity flow and great turbulence can readily carry sand and small gravel temporarily in suspension, and will move immense boulders as bed load, whereas with normal stream flow the water may be clear with practically no suspended load except possibly colloidal matter, and with bed load movement consisting only of small quantities of very fine sand. A major flood can thus deposit enormous quantities of heavy sediment in a reservoir in a short interval with a good percentage of the lighter suspended sediment passing on downstream, particularly in a small reservoir such as Anchicaya. Minor floods will carry less bed load but will deposit a larger percentage of the suspended sediment due to longer retention in the reservoir. Normal flow will deposit not only all the bed load, but practically all the suspended sediment, even in a relatively small reservoir."

"Silting of the reservoir is thus inevitable, but preventative measures can greatly increase the life thereof. The following quotations are taken from the "Handbook of Applied Hydraulics" by Davis, page 132, relative to the "Control of Silt": "

"Only in rare instances is the removal of silt from a reservoir by mechanical means justified economically. The removal of silt, once deposited, by reservoir sluices has never been particularly effective."

"Usually though, watershed control is the only practical solution. In such cases, there may be economic justification for special check dams and debris barriers. Another solution is the construction of a silt barrier above the head of the reservoir. Owing to the tendency of debris to be deposited on a slope, there may develop large effective capacities."

"Anchicaya reservoir, with its extremely limited capacity and a mean stream flow sufficient to fill the reservoir 1.5 times a day, presents a particularly difficult problem in that even a very small percentage of silt in the flow will result in serious sedimentation in a relatively short period of time. The sharp V canyon surrounding the reservoir presents no possibility of removing sediment to adjacent areas. The known rapid sedimentation and the small reservoir capacity to be gained would probably never permit economical justification for raising the dam, although low flashboards could probably be used to advantage at some future time.

There thus appear only the following solutions to the sedimentation problem:

1. Prevent as much of the sediment as possible from reaching the reservoir.

2. Utilize the sluice gates during periods of heavy flow, or of highly muddy inflow, to permit as much as possible of the suspended load to pass downstream.

3. Stop the continued deforestation which is taking place in the watershed, particularly that of the Digua, and prevent any future deforestation in the upper Anchicaya basin.

4. Remove with a dredge as much of the sediment as is practical, discharging it downstream of the dam to be carried away by floods or water overflowing the dam.

It appears that all of these methods will be required to retain the largest possible pondage for regulatory storage for the Anchicaya plant in the coming years."

The balance of the report elaborates on the methods outlined, suggests possible debris barrier sites in both the Digua and the Anchicaya, and the future major upper Anchicaya project reservoir, and a possible upstream Digua hydro project called the Engaño, all these based on the prevention of sediment from reaching the reservoir.

The utilization of the sluice gates is also explained and justified. Prevention of deforestation is also given careful consideration and the benefits emphasized, this being the best method of prolonging the reservoir life and to date the most neglected.

Lastly, reasons for obtaining a dredge immediately are outlined and recommended.

The report closes with the statement: "It is believed that the program of work outlined above will accomplish about all that can be expected, and about all that can possibly be economically justified in prolonging the life of Anchicaya reservoir."

The reaction to the report was extremely favorable, and in another report dated December 11, 1957 I described the tentative bid of Ellicott Machine Corporation of Baltimore for a special 12" Dragon type suction dredge and other accessories, and a tentative shore discharge line (later abandoned in favor of a discharge tunnel) economically justifying the purchase by preservation of the peaking capacity of the plant.

Early in 1958 Dr. Lorenz G. Straub, now deceased, a Specialist in Hydraulic Problems, of Minneapolis, was retained to make a review of the sedimentation problems at Anchicaya, and this original assignment was later extended to assist in obtaining a suitable suction dredge for Anchicaya.

Dr. Straub visited Anchicaya in July 1958 and reviewed the entire project with me, obtaining all data and reports available and under date of

October 27, 1958 submitted an extremely interesting report supplemented with photographs, drawings and graphs. For data used in preparing his report Dr. Straub had only three sounding records, the two already mentioned herein, and the third of April 1958 covering only a 6 month period with an average river flow of 72.5 cubic meters per second, and depositing and additional 192,600 cubic meters of sediment in the reservoir. The total sedimentation at the end of the 36 month period after closure of the dam was 1.553.600 cubic meters, with an average river flow of 81.2 cubic meters per second, as against the then existing long term average flow of 92 cubic meters per second. Analyzing the existing data Dr. Straub notes: "With all of these comparisons taken into account it must be accepted that the average annual rate of sedimentation in the reservoir is likely to be of the same order of magnitude as the three year average, or about 700,000 cubic meters annually. It must be further recognized by a review of earlier records that if the reservoir had been in operation during the hydrologic year October to September, 1949-'50, a far greater sedimentation rate would have occurred, because for that year the runoff averaged 123 cubic meters per second, or about 135 percent of the long term average. Under such circumstances, the sedimentation in one year might well have been greater than occurred for the entire three year period."

Dr. Straub in the report also notes that the three year sedimentation period being studied includes part of the longest drouth period in the Anchicaya records. This extremely dry period includes March 1956 and terminates with May 1959, a 39 month period with average flow of 69.5 cubic meters per second, and includes the lowest 12 month period of record, April 1957 through March 1958 in which the average flow was 62.8 cubic meters per second. Observations made on the Digua river during construction of the debris dams clearly showed that in periods of low flow, with the water clear, there was practically no movement of bed load and no deposition of sand or mud. A shallow pool some 20 meters long and 12 meters wide created in the river channel by an added lift in the dam, showed nothing but organic debris, largely leaves, in two months time. On the contrary, every flood over the debris dams left immense deposits of sand and small gravel above the normal stream level above the dam, and these gradually washed downstream when the stream returned to normal.

Dr. Straub describes the normal situation in the Digua river before the debris dams were constructed as follows:

"A notable feature of the Digua is the so-called playa or beach area, which encompasses a stretch of about 6 kilometers upstream from a constricted section near the river mouth. Large quantities of gravel are deposited in the playa area; it has a relatively flat slope. During low flows, the river channel entrenches itself into the gravel bed. The conditions observed on the Digua are normal for a situation of this sort where there is a rigid constriction in the river channel which upstream has an erodible bed and a much wider channel. During high river flows the constriction produces backwater upstream in the much wider river channel. The wide channel in turn has much lower sediment transporting capacity for a given discharge than the normal breadth channel, resulting in a flattening of the slope and accumulation of sediment much the same as takes place at the head of the reservoir. The finer materials are, of course, carried entirely through the river length during all flows."

Dr. Straub's report goes carefully into an analytical study of the available data, supplying various formulae quite often developed by him in his various previous studies in the field and the laboratory. These are used to analyze the conditions at Anchicaya supplemented by tests made in the hydraulic laboratory to duplicate Anchicaya conditions. He calculates the sizes of sediment, gravel, and small stones which can be moved into the reservoir with varying channel widths and flow velocities, and supplies a wealth of technical information, all closely confirming our known experience at Anchicaya. Unfortunately, only a few portions of the voluminous report can be included herein.

Of the various tables in Dr. Straub's report, the three included below are quite important and informative.

TABLE I

Ability of the Anchicaya River to Transport Bed Load Materials of Various Sizes During Intervals Between Reservoir Sedimentation Surveys.

River Breadth 30 meters River Slope S= 0.0158

Interval Between Surveys	% of Time in Interval during which Transportation Capacity of River was Adequate to Transport the Specific Sediment Sizes.		
	3 inch diameter	6 inch diameter	12 inch diameter
20 Months April 1955 - December 1956	95	33	2.1
10 Months December 1956-October 1957	73	7.6	0
6 Months October 1957-April 1958	81	17.5	0

Sediment survey intervals were on Mid-Month basis.

built in stages to avoid trapping too much fine material instead of the heavier gravels as intended. The initial stage was 4 meters. It was later raised to 8 meters with sluiceways at 7.2, then the right position was raised to 9 meters in 1961 as it still exists today since not yet passing heavy bed load over the 7.2 meter high spillways.

The instant success of this first debris dam, only partly completed, fully justified a second dam further upstream. The site chosen was number 3 of a tentative series of 4 studied. Here there was a rock ledge on the left bank well suited for location of a concrete spillway, then a channel of unknown depth to rock, then a hard rock right abutment. The proposed design here was to construct the spillway, with temporary crest at 2.2 meters above the river level, then to use a riprap section between spillway and right bank with crest at 5 meters, ultimately to be covered with concrete on both upstream and downstream faces. This dam was practically completed in 1960, and after several floods passed over the dam with perfect safety, the largest flood of record on December 12, 1960 created a flood crest of about 2-1/2 meters depth over the riprap crest, removing therefrom and depositing downstream riprap of up to over 10 tons in weight. Emergency measures then had to be taken to return the flow to the sluiceways, bridge with a heavy concrete beam the gap caused by the loss of riprap, then replenish the riprap and the upstream gravel fill, and immediately place the concrete cover, all of which was completed by the middle of 1961. In this dam, the upstream gravel deposit practically kept pace with the construction, and the gravel-boulder upstream backwater curve was already well developed before final completion. The height of this dam raising the water level

4 meters was controlled by the road elevation some 300 meters upstream, and the roadway, despite raising about 50 cm, has been covered with water during several floods. This dam could be raised several meters, but any increase in height would require raising several hundred meters of highway adjacent to a nearly vertical hillside.

The very rapid increase in slope of the backwater curve above both of these dams soon demonstrated that there was no vital need, except greater security, of placing dams at sites 2 and 4 originally planned since these sites had somewhat less water level capacity, and the boulder backwater curved had quickly raised the river bed at these sites by more than two meters.

No exact measurements of the sediment trapped behind these two dams are possible but approximations from topographic maps indicate that probably over 500,000 cubic meters total sediment, mostly bed load, had been trapped by the end of 1967. Almost all bed load now passes the upper dam, but the downstream Digua I continues trapping the heavier bed load, and can retain a large additional amount of heavy bed load when finally raised to full height.

THE ANCHICAYA DREDGE

Everyone finally admitted that the only way to retain the Anchicaya reservoir was to remove the suspended load sediment deposit of around 50.000 cubic meters per month average with a dredge, although mechanical devices were considered. Also, there was general agreement that the lighter sediments could readily be dumped over the dam to be carried away by floods, without any particular hazard until the material dredged became too large. One proposal was to pump the material downstream beyond the power house if it ever became necessary. One major complication was the length of discharge pipe necessary which would greatly increase the dredge size and power requirements. An extremely long floating line would be costly and could be readily lost in a major flood. A long shore line was considered safer for flood hazards, but would be extremely crooked even with a number of small tunnels or open cuts, and would be damaged by local landslides. Since much time elapsed and numerous studies were required, the estimated necessary length of discharge line decreased due to the downstream advance of the heavier sediments. No money was available for purchase of a dredge but IBRD representatives were convinced of the need of the dredge and required a definite plan and cost estimate. Moreover, the success of the Digua debris dams had somewhat changed (unfortunately not permanently) the sedimentation picture. In the meantime I had presented the new idea of a dredge discharge tunnel to greatly shorten the discharge line requirements and the power requirements of the proposed dredge. Thus Dr. Straub was requested to review the new conditions and study the possible use of the proposed dredge tunnel to reduce the size and cost of the

TABLE II

FLOW AT WHICH BED LOAD TRANSPORTATION WILL START OVER AGGRADED BAR AT HEAD OF ANCHICAYA RESERVOIR.

Estimated Bar Slope S=0.0064

Sediment Size Inches.	Breadth of Flow=B B=25 meters	B=50 meters	B=75 meters
3	87,8	176	264
6	245.5	490	736
12	691.0	1382	2073

Flows in cubic meters per second

TABLE III

COMPUTED CAPACITY OF ANCHICAYA RIVER TO TRANSPORT MATERIAL OF 3 INCH SIZE OVER AGGRADED BAR AT HEAD OF ANCHICAYA RESERVOIR.

Assumed Channel Breadth 50 M Assumed Bar Slope S=0.0064

Period	Duration of period	% of time when Bed Load transportation could occur	Accumulative total cubic meters
April 1955-December 1956	20 months	10.7	211.000
December 1956-October 1957	10 months	0	0
October 1957-April 1958	6 months	2.9	6150

Table I shows that the river could transport 3" material to the head of the reservoir 95 percent of the time during the initial sedimentation period, and 12 inch material only 2.1 percent of the time. Table III indicates that

3" material could be transported across the bar at the head of the reservoir only 10.7 percent of the time. Table II clearly indicates that the larger bed load materials can only move across the bar during floods, and this explains the steep backwater curves of gravel and boulders above the debris dams constructed later. Were it not for these backwater bars the quantity of bed load trapped behind the low debris dams would be relatively small. However, it must be remembered that these steep backwater bars could largely be washed down into the reservoir in a really major flood, since readily available, unless the upstream destruction was so great that larger material would replace the existing material and actually increase the backwater bar slope; to date, there is very little backwater bar at the head of Anchicaya reservoir except when the reservoir is drawn down. However, when the reservoir is low, large gravel bars are visible for some distance downstream, with the river confined to a narrow channel quite resembling the normal river channel above the reservoir, and until the reservoir level rises, quite capable of moving bed load similar to that listed in Table I., this condition endangers the reservoir since the larger gravel continues to move downstream in the drawn-down reservoir, covering finer materials capable of being removed by the dredge. Dr. Straub called special attention to this condition, mentioned previously in my reports, since it is one of the bad results of drawing down the reservoir for the production of peak power. When the Calima plant with a large reservoir was placed in operation I recommended keeping the Anchicaya reservoir nearly full at all times, using Calima for peaking, and thereby obtaining more power from Anchicaya with less movement of sediment in the reservoir. This method has been used during the last several years.

Dr. Straub estimated that on the basis of the records then available, the sediment deposited in Anchicaya reservoir would be about 700,000 cubic meters per year with normal flow, but stated specifically that the Anchicaya river was capable of transporting much more than this amount if it were available. From his calculations he estimated that the bed load, which cannot be measured, would be about 17 to possibly 20 percent of the total. Already included herein are a couple of paragraphs from my November 17, 1957 report describing suspended and bed loads, wherein is mentioned that there is no real dividing line between the two classes of load, since a tumultuous stream can readily carry heavy sand and small gravel in suspension, whereas a flat quiet stream even with larger flow may not be capable of moving sand as bed load. However, Dr. Straub apparently only considered large particles as bed load at Anchicaya, since he mentioned that in the initial sedimentation period of 20 months, with total sedimentation of 59.390 cubic meters sedimentation, about 10,000 per month was attributable to coarse gravel deposits brought into the reservoir as bed load. He specifically recommends one or more hydraulic suction dredges to remove the 50,000 cubic meters per month deposit of sediment. To remove the gravel input also, he estimated that two 12" dredges would be required. He also recommends the construction of low debris dams on the Digua river to prevent the bed load from reaching the reservoir, frankly stating: - "One of the quite obvious steps to prolong the life of the reservoir is to prevent the gravel from escaping the Digua river as far as economically possible."

Relative to use of bottom outlets in the dam to discharge sediment he writes: "At times on this reservoir and others there have been suggestions of flushing the sediment out of the reservoir by means of a bottom outlet. In the writer's opinion, this is quite impractical from many points of view. Once the sediment has been deposited for any appreciable length of time, even though it may be in the nature of mud composed of fine silts and clay, quite high velocities are needed to put it back in suspension and motion through a bottom outlet. Moreover, the Anchicaya dam was not built with such functional operation in mind."

Relative to sunken debris and tree trunks: "In case of dredge operations in the reservoir, this must be undertaken in full recognition of having to cope with the removal of water-soaked trees, which apparently tend to come into the reservoir and settle to the bottom and be covered by fine sediments. These will have to be removed by some type of floating equipment involving the use of a clam-shell or orange-peel bucket or similar appurtenances." All of these items were previously covered in my reports on the sedimentation problem. The final recommendations were almost identical with those previously quoted herein from my November 1967 report and need not be repeated here. His closing paragraph follows:

"In consideration of all aspects of the present situation, it would seem necessary to reconsile one's self to the fact that remedial measures to be taken in connection with the sedimentation of the Anchicaya reservoir are a matter of expediency to take care of the peak load power requirements of the Cali area for as long a time as possible until the demands can be met by other means, including the possible construction of a proposed power development further upstream on the Anchicaya river. The measures that would be taken then would be in the nature of delaying action rather than permanent remedial measures. The present Anchicaya development would then eventually revert to a run-of-the-river plant without being obliged to furnish peak power.

THE DIGUA DEBRIS DAMS

My November 1957 report proposed construction of the first debris dam in the 300 meter restricted section of the Digua river, just above its junction with the Anchicaya, and below the last major playa section of the Digua. This restricted section terminated in a natural barrier of immense quartzitic blocks creating a fall of about 2-1/2 meters height at normal flow, and undoubtedly controlled the elevation of the large playa above the restriction. Early in 1968 the jungle was cleared and trails were constructed to permit study of the rock structures in the restricted area, and three possible sites were studied, and the natural barrier was chosen as site for the first core drill hole which confirmed that the solid rock was at least 10 meters below the surface. This depth eliminated any possibility of a dam resting on rock throughout unless a diversion tunnel was used, and this would have been too costly. Thus it was decided to build a dam bridging the deep canyon between hard abutments in a site about 60 meters further upstream where an immense quartzitic block existed in mid stream. Concrete pilasters were constructed on this block to place the core drill about 4 meters above stream level and drilling revealed that the block rested on gravel about 4.5 meters below water, and that the solid rock was at about 11.0 meters. The right abutment was a hard rock nearly vertical cliff about 5 meters from the center block, and the left abutment had solid rock at 8 meters. This site was considered satisfactory for a very unusual type of overflow dam slightly arched between abutments, the center resting on the big rock block, the right half on gravel at 3 meters below the water surface, and the left half part on solid rock and gravel, and both abutments against hard solid rock with a ski-jump on the downstream fall 1.5 meters below water. When Dr. Straub visited the site in July 1958, construction was already under way using a method I had completely described in a memorandum written in June 1958. This method consisted of switching the river through sluiceways one side or the other of the center block as the dam progressed upward. Careful planning of every move permitted excellent progress despite numerous floods passing over the dam. The dam stopped all downstream movement of sand and gravel as soon as it reached river level, causing a surprising 30 to 50 centimeter lowering of the flow level all the way downstream to Anchicaya reservoir as all sand and small gravel was washed out completely. This definitely confirmed my opinion that the upper Anchicaya supplied only a very small percent of the total sediment reaching the reservoir. Previous exploratory flights over the jungle covered upper Anchicaya had revealed no sand bars, only 2 major slides in perhaps 300 km^2 of area, and almost continuous "white water" in the river indicating a boulder filled channel. Our opinion was that the Digua watershed, already badly deforested, supplied only about 30% of the river flow, but 75% of the sediment. We later increased this to about 80%. This Digua #1, also called K-81, was planned as a massive dam 12 meters wide at the base 3 meters below water level with a wide ogee crest at 7 meters above water, to be

14" oversize dredge then under consideration.

Dr. Straub released his equally interesting second report on June 4, 1960. For this report he had available two additional sediment reports as follows:

Period	Time	Added Deposition of Sediment	Monthly Average	Daily Flow
Mid April 1958- Mid January 1959	9 months	351.900 m^3	39.100 m^3	77.1 $m^3/sec.$
Mid January 1959 Mid February 1960	13 months	415.900 m^3	32.000 m^3	84.2 $m^3/sec.$

Dr. Straub noted that apparently the Digua dams prevented about 10.000 cubic meters per month of heavy sediments from reaching the reservoir despite larger average river flows, and wisely or unwisely reduced the estimated sediment to be removed by the dredge to around 40.000 cubic meters per month, but did not mention any specific dredge size. (Luckily we finally retained the 14" size.) He also made a very careful mathematical analysis to determine the best practical slope and shape of the proposed tunnel invert, if concreted, to handle the maximum size gravel expected, and recommended that the slope of the dredge tunnel should be greater than 5 percent, and up to near 7 percent if possible. He also stated that the shape of the invert would have little influence on the carrying capacity, and since heavy gravel loads more or less smooth out bottom irregularities and establish a relatively smooth bottom, possibly the invert need not be concreted. However, he definitely recommended making provision for adding about 10 cubic feet per second flow to guarantee transport of large particles if ever required. These recommendations caused no particular if any changes in the preliminary design of the dredge discharge tunnel or the entrance tower proposed which had two 8" valves for admitting extra flow from the reservoir, and two 36" square slide gates to admit large flows if ever required. Dr. Straub had used my proposed tunnel size of about 1.0 meter wide by 1.5 meters high in his calculations and his only new recommendation was an increased slope which was readily obtained at practically no added cost. Thus, since his report fully recommended the use of the discharge tunnel, the revised plan was quickly approved by the Anchicaya Board, and we were authorized to proceed with the tunnel, the entrance tower, the wharf and roadway leading thereto, and the shore anchors, all to be constructed by Anchicaya crews. After some study of the dredge problem, somewhat complicated by special Anchicaya problems such as operation from shore anchors, a 25 meter dredging depth, and a constantly varying water level due to peak power demands, a more liberal plan of requesting somewhat informal bids was used where bidders were invited to discuss their proposals and possible modifications thereof. As a result a contract was finally awarded to the Ellicott Machine Corp, of Baltimore, for a specially designed Dragon type 14" Hydraulic Dredge with underwater hydraulic motor driving the cutterhead, and "outrigger" Sponson tanks as stabilizers with an "A" frame support for the sheaves for lifting the ladder. Also included were some spare parts, 300 meters of 14" discharge line complete with pontoons, various bends, ball joints, quick disconnect joints, a specially designed landing pontoon, and a service boat.

Many special features had to be considered in designing the dredge and it must be noted that the final product was a combination of ideas and suggestions of a large group of specialists including Dr. Lorenz G. Straub, Consulting Engineer, of Minneapolis; Ole Erickson, Dredge Designer of Tampa, Florida; Robert S. Clas, Vice-President of Ellicott Machine Corp, Baltimore; Carl H. Giroux, Dredge Specialist and Consulting Engineer of Washington D. C.; and the writer as representative of Anchicaya and completely familiar with Anchicaya conditions and problems. The detail design work and fabrication was ably handled by the Ellicott Corp, and assembly upon the job was with Anchicaya crews directed by an Ellicott engineer, Mr. Grant Leeson, who remained at Anchicaya two months after the dredge was placed in operation in August 1962 instructing the operating crew. The equipment met all required tests, was of excellent quality, and has operated to date with relatively minor repairs and overhead , but a major overhaul is due this year.

The dredge was shipped in factory assembled pieces suitable for transport to the reservoir, and was assembled on and adjacent to the small wharf, using a P & H dragline equipped as a crane. The main section consists of 6 tanks bolted together forming an assembly 17.68 meters long, 6.71 wide and 1.83 high. Mounted centrally and low is the main pump with two diesel engine drive, forward and at deck level is an equal diesel engine driving an auxiliary water pump, degassing unit, oil pumps etc. Further forward and also completely aft are the multiple winches for the operating cables at deck level. Further forward is the hinge joint for the 37 meter ladder and the rubber hose for the suction pipe, and at each side the large trusses connecting the dredge with the Sponson tanks. The ladder, suction pipe, and trusses all contain a 10 meter removable section to adjust the dredge for more shallow dredging, but this feature has never been used to date. The degassing unit is especially required to remove the gas released by the decaying organic matter which would otherwise seriously decrease the pump suction. In the reservoir, gas bubbles continually rise to the surface, and when the water level is being lowered rapidly, the water almost appears to be boiling. The gas is combustible, probably "marsh gas", and at one time I wondered about concentration thereof as an explosion hazard, but the gas is so light it dissipates very rapidly with no hazard whatsoever, and the bubbling seems to have decreased in quantity.

The only operating difficulty experienced which was not fully anticipated comes from battered pieces of trees, around 2 to 3 feet long and 4 to 7 inches diameter which enter the cutterhead, then lodge in the knife compartment just ahead of the pump impeller. Since too large to be cut or broken, these obstructions quickly collect smaller debris requiring stopping of the pump, opening the quick removable cover, and extracting the trapped material. This may happen few or many times a day depending upon what is encountered in dredging, and often causes a lot of lost time. In an effort to correct this condition, large bars were welded in the spaces between the cutters of the cutterhead. This proved impractical since banana plants, branches, and vines quickly wrapped around the cutterhead and lifting the ladder to clear the cutterhead was found to take more time than removing the small logs from the knife compartment. During floods floating debris hangs up on the ladder, trusses, and cables to a dangerous degree and stops dredging until such debris is removed, usually the discharge line on pontoons is quickly disconnected and anchored to shore for safety, only one small piece having been carried away over the dam.

The expected problem of sunken logs and trees has been less than anticipated but in portions of the reservoir near the discharge tunnel entrance, which has been dredged several times, the bottom of the excavation is almost "paved" with sunken logs. Contrary to conditions in temporate zones with large seasonal changes, the tropical jungle remains permanently green, and "feeds itself" by the continually falling leaves and debris, and rotting trees, practically all of which remains moist and heavier than water. Almost all cut trees are heavier than water. Leaves falling in the water rarely remain on the surface. Most of the battered tree trunks carried down the Anchicaya barely float, largely because of turbulance, but usually sink upon reaching quiet water. We have always estimated that about 10 percent of the deposits in Anchicaya reservoir are of organic origin, and Dr. Straub has expressed the same opinion. Luckily, the smaller organic materials rapidly decompose in the relatively warm water (about 23° C). Our original plan at Anchicaya was to mount a winch, boom and some sort of orange peel bucket or grapple on the dredge, but this proved completely impractical because of the operating cables attached to shore anchors. Then it was decided to mount the handling equipment on a barge, but only recently has this equipment been fabricated and placed in operation due to the urgent need of removing sunken logs from in front of the sluiceway trashracks at the dam. A letter just received mentions removing tree trunks up to 2 feet in diameter and 14 feet in diameter from in front of the trash racks, with even larger trunks in view but not yet removed. Many short pieces of lumber were also removed, largely carried away from various construction projects by floods etc., since all lumber available is heavier than water, and any board dropped in the river usually disappears and is carried on downstream.

OPERATING PERIOD - AUGUST 1962-1967.

Late 1962 was the end of the active construction period, with the dredge in operation and the two Digua debris dams constructed, and already nearly full, and the backwater curve of heavy gravel continually steepening with deposit of larger gravel and cobbles. This rapid build up of the backwater deposits made any additional low debris dams almost useless. I proposed raising the Digua 3 dam as an alternative to constructing proposed Digua 4, but this would have required raising some 700 meters of highway. Another proposed site was at a big bend between Digua 1 and Digua 3 dams where there exists a narrow ridge perfectly suited for a short tunnel, later to become a spillway or portion thereof, to permit a large rock fill dam in the bend, high enough to swamp Digua 3 if desired, but a long complete relocation for the highway would be required. Neither project was considered. The sediment deposits continued to increase in the reservoir. Original operation of the dredge was only a single 10 hour shift. Operation of the dredge became a routine and lacked any inspiration. Even the conduction tunnel trashracks were found to be nearly sealed on two occasions. The funnel shaped hole in front of the trashracks continued to become more hazerdous. My recommendations for more operation of the dredge bore fruit but never was the dredge employed full time, and we continued to lose reservoir capacity to sediment due to the increasing amount reaching the reservoir. Destruction of the jungle continued and was rapidly spreading into the upper Anchicaya watershed. In the October 1964 soundings, the total remaining capacity of the reservoir had already been reduced to about 1.530.000 cubic meters. This survey was made just after the very disastrous flood in the Rio Blanco area, a tributary of the Digua river, which occurred on the night of October 16, and morning of October 17, 1964 and placed an estimated 60.000 cubic meters of sediment in the reservoir and left in the river possibly an equal amount which ultimately reached the reservoir. The total flow reached a peak of 638 cubic meters per second at 5 a.m. on the Danubio gaging station but apparently the maximum discharge of the Rio Blanco was around 400 cubic meters per second. A complete report was made on this highly unusual flood since Anchicaya had for two previous years contracted for cloud-seeding in an effort to obtain more flow in the river, and this Rio Blanco started just short of 24 hours after the smoke pots were shut down. During the contract period we had experienced several highly and unusual damaging floods in small areas, and an area just westward of the Anchicaya basin had apparently received an above average precipitation. In checking these results we had been informed that the effects of seeding could result in precipitation as much as 24 hours after seeding. The Rio Blanco flood was thus a border line case, and as is usual, there was no way to prove what really happened. In any event, the contract was not renewed. There were 43 new landslides reported in the area covered by the Rio Blanco flood, mostly in soft materials of an orange color readily identified. The regimen in the Rio Blanco was largely destroyed. Our wharf area at Anchicaya received a deposit of 20 to 25 centimeters of this orange mud and several mysterious mud balls were noted, where less than a meter of water covered the wharf for something less than 24 hours, this gives an idea of the enormous suspended sediment content of this flood, with water, which had already passed-through two kilometers of relatively quiet reservoir. The previous maximum deposit recorded was 15 cm. during a larger flood of longer duration. The Rio Blanco flood carried an enormous amount of silt and debris, uprooted trees were left along the river banks, the conduction trashracks were nearly blocked with debris. An inclined 3/4" cable used for concrete chutes, attached to the left abutment of Digua 1 dam accumulated as much debris that it snapped. My reports repeatedly warned that a single flood could deposit more sediment in the reservoir in a day than normally is deposited in a month, and this flood did exactly that. Dr. Straub agreed with me on this and also my statement that one really major flood could fill Anchicaya reservoir completely. However, Dr. Straub did not accentuate this risk, nor did he specifically call attention to the fact that the number of large floods in a period between soundings greatly influenced the sediment deposit. Having witnessed 4 major floods in my life, I know what can happen, and certainly hope that no major flood hits Anchicaya since even a 2000 meter flood will probably flood the plant and possibly completely fill the reservoir.

I was somewhat irritated by this long operating period with worsening conditions and time running out on the reservoir, with no action whatsoever to better conditions, demonstrated by a complacency or mañana attitude. Thus, in November 1965 I wrote a 10 page memorandum describing the increasing seriousness of the sediment and other problems, and the approach of the run-of-the-river condition at Anchicaya. Also I once again urged consideration of my upper Anchicaya project, first presented in 1956-57, and also suggested the possibilities of placing the proposed plant below the Anchicaya dam to lessen the difficult sediment problem, or just above the dam, with suitable works to utilize the existing plant. However, I stated that the plant located on the upper end of Anchicaya reservoir was still feasible, but would have problems with sediment in fully utilizing the existing plant. As immediate partial remedies I again suggested raising Digua 1 to the full height of 9 meters, and Digua 3 by at least 2 meters. Lastly was the full operation of the dredge 24 hours a day, and the obtaining of a "hard pushing" dredge operator from the Ellicott Corporation for a few months for additional training of operators to secure better production. This report also appeared to have little influence, but along towards the end of 1966 I noted a revival of interest in both the upper Anchicaya project and the Anchicaya reservoir. This was probably stimulated by realization that the proposed intertie line, then destined to supply the Cali area with power from Bogota was being seriously delayed and even when completed in the first stage, would probably not suitably supply the required power.

Thus, on January 17, 1966 and finally on February 15, 1966 I issued long memorandums covering various methods of preparing the Anchicaya plant for run-of-the-river conditions, for obtaining more power from Anchicaya by coordinating with the Calima plant which had been recently placed in operation, and again presenting my upper Anchicaya project as by far the best way to solve the power problem. I do not know whether these last group of reports were instrumental or not in the sudden "renaissance" of my "pet project", but definite results started early in 1966

THE RENAISSANCE

Early in 1966 the real "renaissance" of Anchicaya, and the upper Anchicaya project started a wave of activity. It suddenly developed that the CVC organization of which Anchicaya is a part was at long last interested in the upper Anchicaya project which I had proposed, and former Anchicaya Manager, Luis E. Palacios had tried to promote as more favorable than the CVC Calima project some 8 years previously. Rapidly trails were cut into the area, surveys and mapping were initiated, stream gaging stations were established, preliminary geological investigations, all existing data on weather, stream flow, sediment records were assembled and the upper Anchicaya Preliminary Feasibility Report was issued on October 31, 1966, and a large Feasibility Report jointly prepared by CVC and Acres International Limited of Niagara Falls, Canada was issued in April 1968.

This project uses a damsite marked on my first preliminary plan prepared in 1957 as an alternate, but which remained unstudied then despite a statia survey carried in to near the damsite. My projected damsite, further down the river, was also studied by CVC, but was found to have a somewhat smaller reservoir, less head, and proved less economical. The CVC power plant is on the exact location I proposed in 1957, on the upper end of Anchicaya reservoir. The new plant will have a dam with normal pool elevation of 646 meters, an active storage between 646 and 615 meters of 30 million cubic meters, and a dead storage below 615 of 15 million meters. The power tunnel 5.5 meters inside diameter will be 8.3 km. long terminating in a 460 meter inclined shaft and 240 meters of steel lined tunnel. The underground power plant will have four 85 Mw units for a total of 340 Mw, an average continuous output of 201 Mw, and an annual energy production of 1760 x 10^6 kwh at a cost of 4.1 US mills per Kwh. The average flow is estimated at 56.0 m^3/sec or about 2/3 of that at the Anchicaya Danubio gaging station, conforming almost exactly with my original estimate. The project has already been partly financed and full financing is imminent. Initial construction work is already under way, and probably heavy construction will start early in 1969.

This intense activity has had a decidedly vigorizing effect on Anchicaya personnel. A new station chief has taken intense interest in the dredge and sediment problems. It was discovered that the trashracks were badly encrusted, apparently due to natural causes and unsatisfactory operation of the trashrack rake. The area in front of the sluiceway trashrack was almost completely filled with tree trunks, timber, and debris. The funnel shaped hole at the intake tower was in a very hazardous condition as I had previously mentioned in various reports. Soundings were used to map the sediment. Divers were used to check conditions. Plans were made to remove by stages the generally small grained light sediment between sounding section 13-14 and the dam. This section had been purposely left high in previous years when Anchicaya was the only major source of power to prevent trunks and major debris from moving downstream into the funnel shaped hole around the outlet tower. The completion of the Calima plant permitted safe operation of removal in this area, and also around the outlet tower. Three shift operation of the dredge was approved, and an experienced dredge operator was obtained from Ellicott to again demonstrate efficient dredge operation. Additional dredge discharge pipe was obtained. Lastly, a barge with a special clam shell bucket was assembled and placed in operation removing sunken logs from around the outlet tower. All of these items which I had previously recommended - now became factual, with excellent results. No report is yet available as to total gain in storage due to 1968 operations, but a letter recently received mentions that approximately 800.000 m^3 of fine sediment has been easily removed from the downstream end of the reservoir.

A drawing attached shows the successive sediment profiles and quantity tables obtained from sounding records taken since closure in April 1955, with additions of the latest information relative thereto. Other maps greatly reduced show the entire reservoir with sounding section locations. Larger scale maps of the downstream end of the reservoir show the dredge operating area, the shore anchor locations, and the method of attaching the dredge thereto. Other drawings show typical progressive sediment cross sections for two sounding sections. Maps and profiles show conditions adjacent to the outlet tower, Various other maps and tables are also included.

RECOMMENDATIONS FOR FUTURE RESERVOIR MAINTENANCE

The proposed development of the upper Anchicaya project as now planned demands the maintenance of Anchicaya for as long as possible, thus particular study was given to the sediment problem, and six single spaced pages cover the analysis and recommendations in the April 1968 Alto Anchicaya Project Feasibility Report, excerpts of which are quoted as follows: "this power plant (anchicaya) appears to be seriously endangered by the ever-increasing sedimentation of its reservoir, which within a period of 12 years has caused the almost complete loss of pondage, forcing the plant to change from peak load operation to a run-of-the-river plant. --- Continued sedimentation may cause an appreciable increase in the riverbed elevation at the tailrace outfall of the scheme of development for the Alto Anchicaya Project."

"The present (March 1968) water storage in the reservoir is estimated as about 1,000,000 m^3. At the rate of net deposition in the reservoir which has prevailed in recent years it can only be a short while before the existing power tunnel intake is blocked and the power plant is rendered useless. For a high flood of the same order of magnitude as the highest of record (1290 m^3/sec.) a deposition of about 100.000 m^3 of sediment has been estimated."

"Recommended measures: - the existing 14 inch Ellicott suction dredge should continue to remove deposited materials from the reservoir. Information available on the existing dredge indicates that it should be possible to remove as much or even more material from the reservoir as there is flowing in."

"With the present equipment, material up to one inch in size may be handled effectively. All larger material cannot be handled and will deposit permanently in the reservoir. If it were possible to make the volume of the reservoir presently occupied by fines available for storage of coarse sediments, then the complete siltation of the reservoir could be delayed by an estimated additional 25 years. Coarse materials are creeping in from the head of the reservoir, depositing on top of layers of previously deposited lines. When a sufficient volume of coarse materials exists over fine layers, inversion of the two materials may be carried out by injecting high pressure water into the fines, causing the coarse sizes to sink and the fines to float to higher elevations where they will be picked up by the natural current in the reservoir and carried further downstream to then be removed by the suction dredge. When the deposition of coarse materials in the river begins to raise the water level at the location of the proposed Alto Anchicaya tailrace outfall, canalization of the river through the sediments downstream from this location is recommended. It has been estimated that all of the remedial measures described would postpone a possible interference with the full utilization of the presently available head by the Alto Anchicaya Plant for approximately 25 years."

Remedial measures for ultimate use: - "Suitable mechanical equipment would be installed for continuous removal of large size deposited material in an area upstream from the present location of the suction dredge. Fine material would continue to be removed by the dredge and the area of the reservoir in front of the power tunnel intake would be kept free of sediments by the periodic opening of the bottom sluices of the dam, the coarse materials would be transported by an aerial ropeway into an adjacent valley."

Personally, I believe there is a good percentage of "wistful thinking" involved in the future planning for maintaining full flow through the existing Anchicaya plant, and I would have preferred that the new plant be constructed a short ways below the existing dam, utilizing the total head and consigning the existing plant to a secondary roll, or else locating the new plant just above the dam, with discharge duct across the dam or reservoir to a specially created small forebay for the existing plant and skimming devices to utilize the remaining Digua flow only when reasonably clear.

I heartily approve the inversion plan for lowering the heavy sediments, but discount somewhat major movement downstream of the sand since the reservoir will normally be retained at near dam crest, with very low reservoir velocities initially or until the backwater rise of the gravel creates greater slopes. The heavy material cover existing over the fines was almost entirely the result of drawing down the reservoir for peak power.

Moreover, I am thoroughly convinced that a major debris dam should be constructed in the Digua after the Buenaventura-Buga highway is completed and traffic can be diverted from the present Simon Bolivar highway.

Lastly, I do not believe that proper consideration has been given to the hazard of a major flood, since I consider that a 2000 m^3/sec flood would swamp the Anchicaya plant, possibly even fill the existing reservoir with sediment, and might carry the existing dredge to destruction. Such flood is a serious possibility.

Another feature is that the Feasibility Report barely mentions the extremely vital deforestation problem on the Digua. However, the following quotation therefrom indicates that at long last, the importance of deforestation has been recognized. "At present the area surrounding the site (Alto Anchicaya) and upstream water courses is thickly vegetated (tropical jungle), and the CVC is taking strict measures to prevent settlement and clearing of forest in the watershed. Settlers have been relocated and all former agricultural clearings have reverted to jungle and will remain in that condition. The new reservoir will therefore not be subject to the severe sedimentation which occurred in the Anchicaya reservoir." Another paragraph indicates that periodic air patrol will check any future entry of settlers or destruction of the jungles.

This lengthy report is actually only a very brief summary of nearly 17 years spent at Anchicaya, largely on transmission line and power plant and heavy construction work but with the major worry concentrated on the ever present sedimentation problem, completely ignored and unmentioned by the originators of the project and the later Consultants.

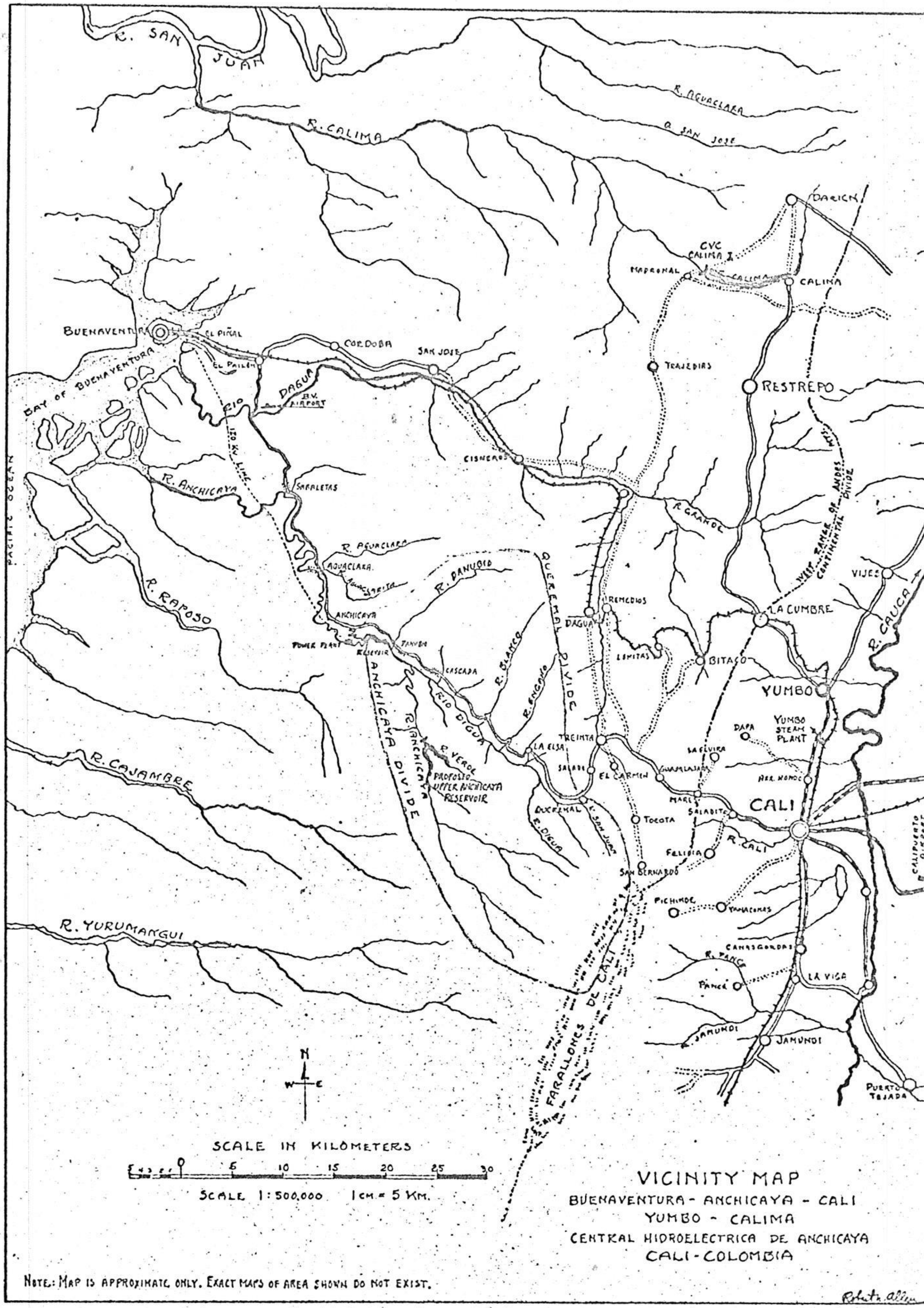
It is hoped that this report will be of assistance to those who may become involved in similar problems in the future.

Respectfully submitted,

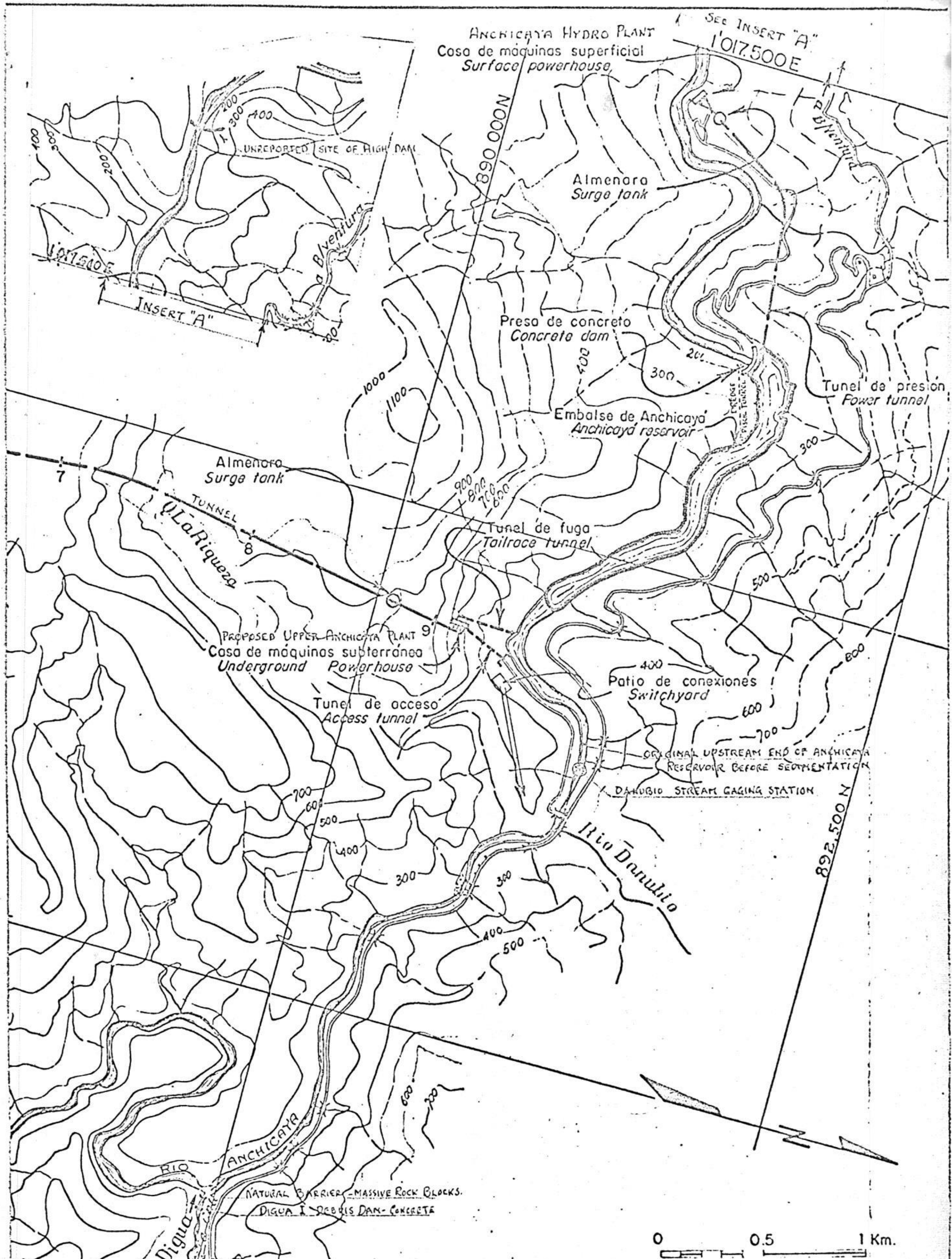
Robert N. Allen

F. ASCE November 14, 1968

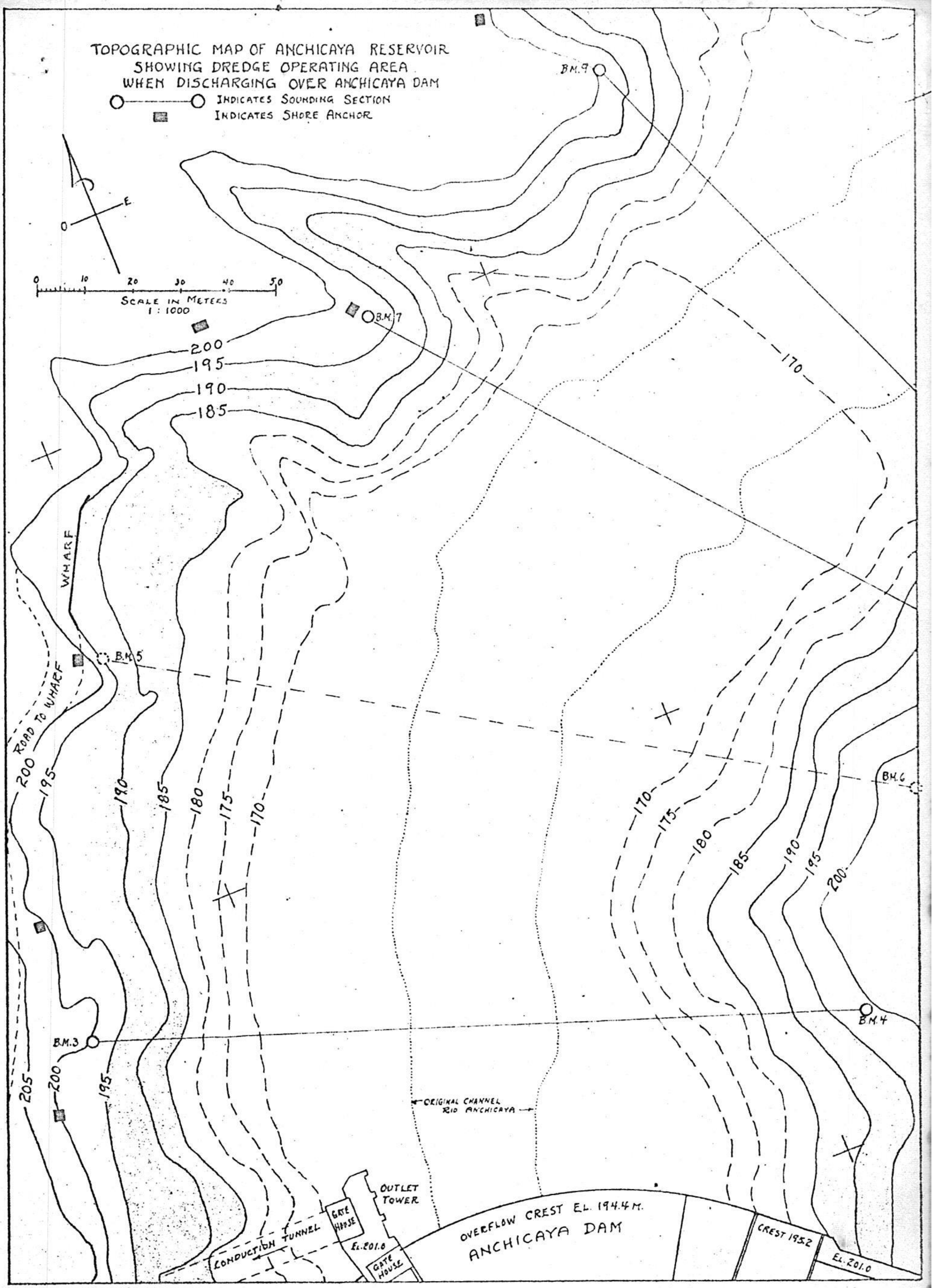
LIST OF DRAWINGS

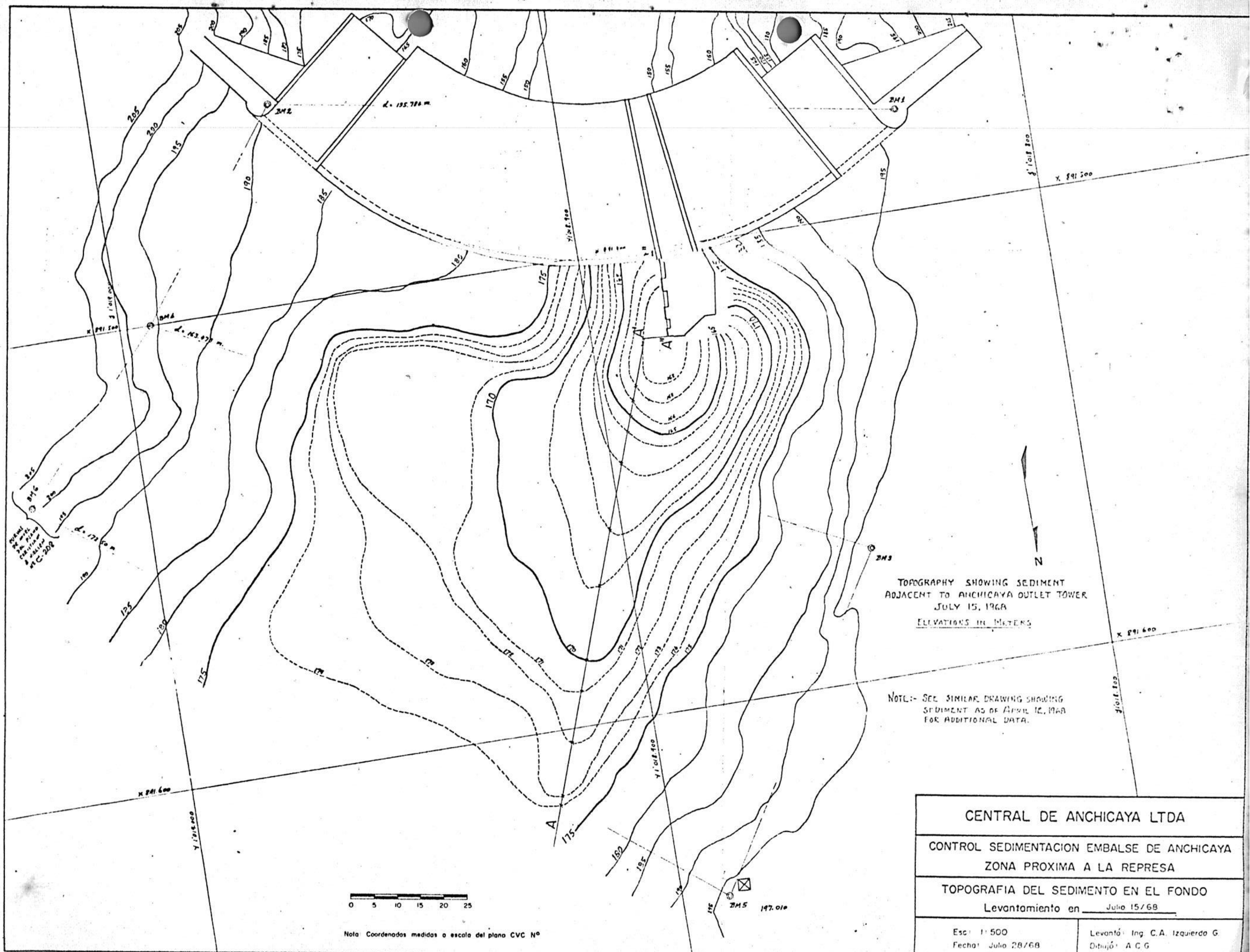


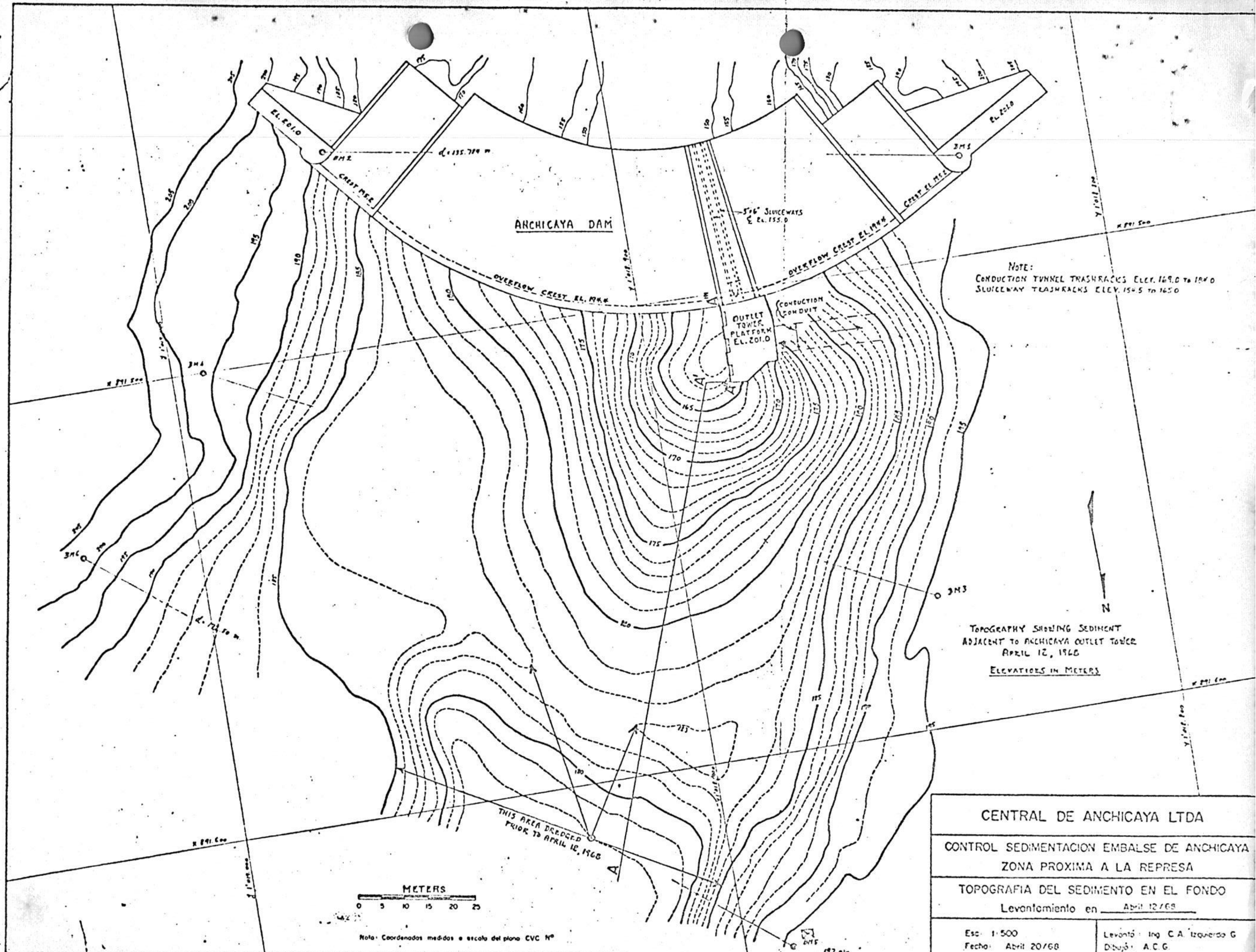
Roberto Allen



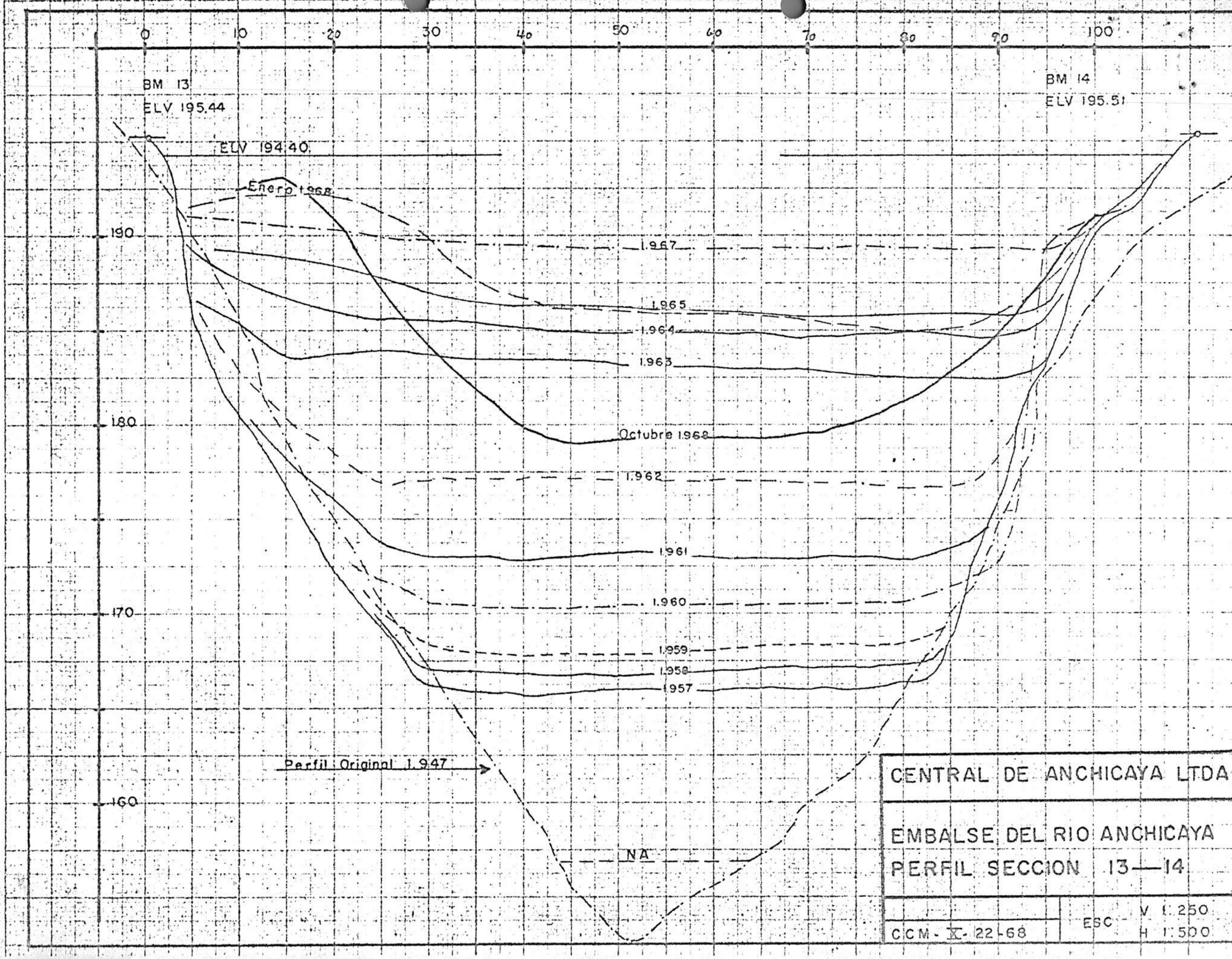
ANCHICAYA VICINITY MAP


TOPOGRAPHIC MAP OF ANCHICAYA RESERVOIR
SHOWING DREDGE OPERATING AREA
WHEN DISCHARGING OVER ANCHICAYA DAM
Indicates Sounding Section
Indicates Shore Anchor
E
O
0 10 20 30 40 50
Scale in Meters
1 : 1000
B.M. 9
B.M. 7
B.M. 5
B.M. 6
B.M. 4
B.M. 3
200
195
190
185
180
175
170
205
WHARF
Road to Wharf
Original Channel
Rio Anchicaya
Outlet Tower
Gate House
Gate House
El. 201.0
Conduction Tunnel
Overflow Crest El. 194.4 M.
ANCHICAYA DAM
Crest 195.2
El. 201.0

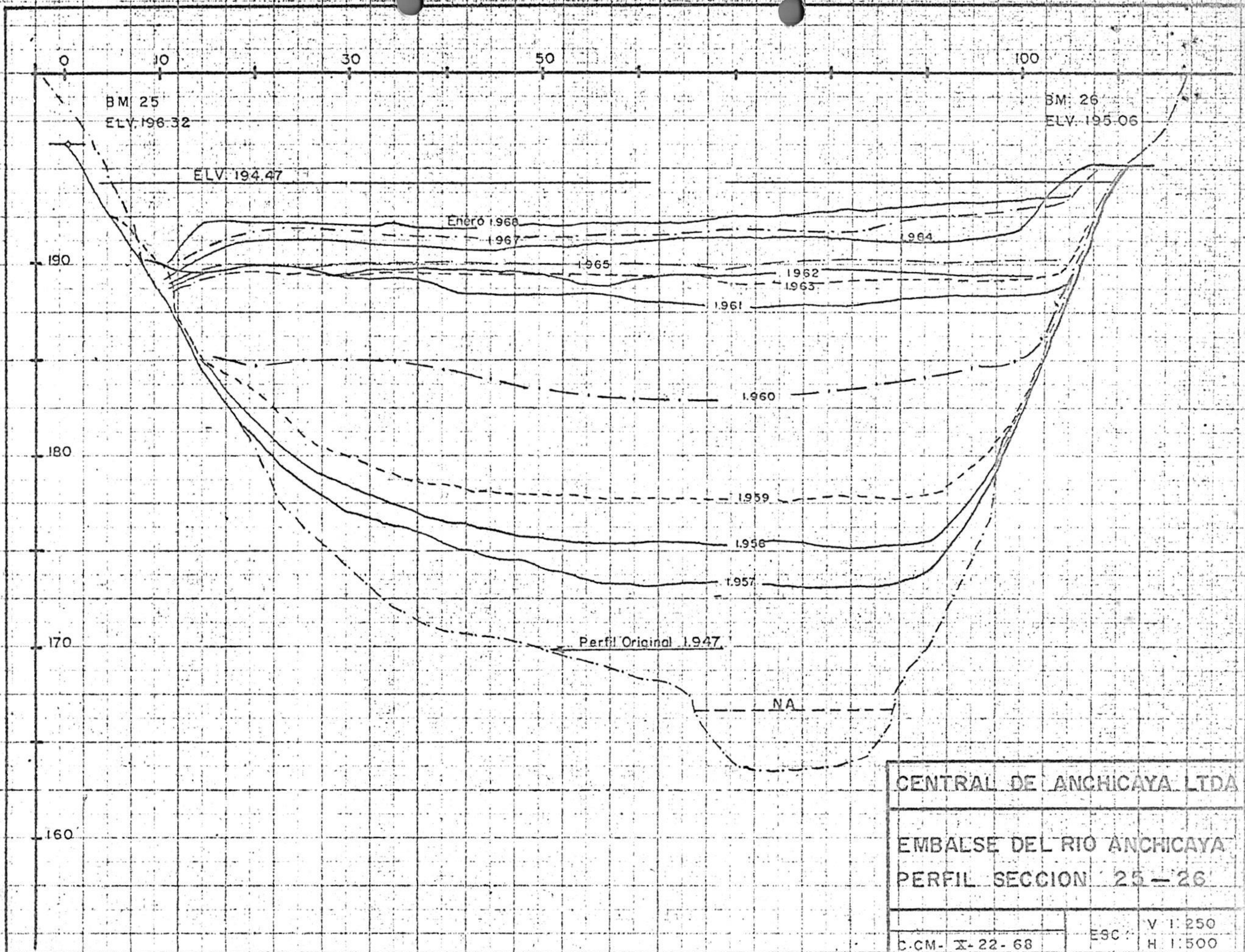

TOPOGRAPHY SHOWING SEDIMENT
ADJACENT TO ANCHICAYA OUTLET TOWER
JULY 15, 1968
ELEVATIONS IN METERS
NOTE:- SEE SIMILAR DRAWING SHOWING SEDIMENT AS OF APRIL 12, 1968 FOR ADDITIONAL DATA.
N
BM1
BM2
BM3
BM4
BM5
BM6
197.010
x 891.500
x 891.600
y 1'018.800
y 1'018.900
y 1'019.000
0 5 10 15 20 25
Nota: Coordenadas medidas a escala del plano CVC Nº
CENTRAL DE ANCHICAYA LTDA
CONTROL SEDIMENTACION EMBALSE DE ANCHICAYA
ZONA PROXIMA A LA REPRESA
TOPOGRAFIA DEL SEDIMENTO EN EL FONDO
Levantamiento en Julio 15/68
Esc: 1:500
Fecha: Julio 28/68
Levantó: Ing. C.A. Izquierdo G.
Dibujó: A.C.G.



ANCHICAYA DAM
EL. 201.0
BM 2
BM 1
BM 3
CREST EL. 195.0
OVERFLOW CREST EL. 194.4
5'x6' SLUICEWAYS
℄ EL. 155.0
OUTLET TOWER PLATFORM EL. 201.0
CONDUCTION CONDUIT
NOTE:
CONDUCTION TUNNEL TRASHRACKS ELEV. 169.0 TO 184.0
SLUICEWAY TRASHRACKS ELEV. 154.5 TO 165.0
N
TOPOGRAPHY SHOWING SEDIMENT ADJACENT TO ANCHICAYA OUTLET TOWER
APRIL 12, 1968
ELEVATIONS IN METERS
THIS AREA DREDGED PRIOR TO APRIL 12, 1968
METERS
0 5 10 15 20 25
Nota: Coordenadas medidas a escala del plano CVC Nº
CENTRAL DE ANCHICAYA LTDA
CONTROL SEDIMENTACION EMBALSE DE ANCHICAYA
ZONA PROXIMA A LA REPRESA
TOPOGRAFIA DEL SEDIMENTO EN EL FONDO
Levantamiento en Abril 12/68
Esc: 1:500
Fecha: Abril 20/68
Levantó: Ing. C.A. Izquierdo G.
Dibujó: A.C.G.



0
10
20
30
40
50
60
70
80
90
100
190
180
170
160
BM 13
ELV 195.44
BM 14
ELV 195.51
ELV 194.40
Enero 1968
1.967
1.965
1.964
1.963
Octubre 1968
1.962
1.961
1.960
1.959
1.958
1.957
Perfil Original 1.947
NA
CENTRAL DE ANCHICAYA LTDA
EMBALSE DEL RIO ANCHICAYA
PERFIL SECCION 13 — 14
CCM - X - 22 - 68
ESC
V 1:250
H 1:500


CENTRAL DE ANCHICAYA LTDA
EMBALSE DEL RIO ANCHICAYA
PERFIL SECCION 25 — 26
ESC: V 1:250
H 1:500
C.CM- X-22-68
BM 25
ELV. 196.32
BM: 26
ELV. 195.06
ELV. 194.47
Enero 1.968
1.967
1.964
1.965
1.962
1.963
1.961
1.960
1.959
1.958
1.957
Perfil Original 1.947
NA
0
10
30
50
100
190
180
170
160

AVERAGE MONTHLY FLOWS OF THE ANCHICAYA RIVER

AT DANUBIO GAGING STATION

CUBIC METERS PER SECOND

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT	ANNUAL
1945 - 1946				75.0	48.0	58.0	119.0	172.0	67.0	39.0	30.0	31.0	
1946 - 1947	132.0	163.0	156.0	118.0	71.0	42.0	58.0	94.0	128.0	106.0	74.0	90.0	102.5
1947 - 1948	155.0	157.0	69.0	62.0	48.0	48.0	86.0	134.0	128.0	68.0	35.0	52.0	86.7
1948 - 1949	96.0	131.0	75.0	71.0	65.0	53.0	77.0	114.0	96.0	72.0	61.0	61.0	80.8
1949 - 1950	147.0	178.0	123.0	99.0	117.0	94.0	104.0	179.0	170.0	96.6	91.0	74.0	122.6
1950 - 1951	146.0	174.0	137.0	72.0	63.0	69.0	69.0	85.0	76.0	70.0	52.0	65.0	89.6
1951 - 1952	96.0	96.0	80.0	82.0	67.0	54.0	90.0	115.0	76.0	73.0	66.0	52.0	78.8
1952 - 1953	96.0	119.0	133.0	75.1	63.0	48.5	73.3	124.3	84.0	63.0	41.8	82.1	83.4
1953 - 1954	141.9	161.6	128.5	70.0	75.8	74.1	107.8	114.6	115.8	66.0	50.8	56.8	96.9
1954 - 1955	150.1	151.2	128.6	95.1	61.6	116.2	158.3	126.7	109.8	93.9	87.0	91.0	114.1
1955 - 1956	136.0	145.0	140.0	92.9	97.7	START * 62.7	68.0	92.1	86.9	55.1	45.7	58.1	90.0
1956 - 1957	114.0	101.0	97.1	74.9	49.1	51.6	o 75.7	79.0	64.3	40.8	31.0	35.9	67.7
1957 - 1958	86.6	111.5	86.6	65.5	40.5	36.7 o	80.3	110.6	58.2	44.7	61.7	39.0	68.4
1958 - 1959	89.5	120.6	98.7	61.0	36.5	36.7	65.7	95.8 * END	144.8	63.2	62.1	43.8	76.3
1959 - 1960	133.3	116.8	106.9	122.7	87.6	65.2	106.8	116.2	75.7	79.5	67.6	57.5	94.6
1960 - 1961	87.8	113.1	111.0	72.9	42.4	48.7	95.4	70.2	81.5	69.7	42.0	58.5	74.2
1961 - 1962	83.7	111.8	99.5	66.0	76.9	73.7	83.9	136.8	89.5	61.9	60.2	64.8	84.0
1962 - 1963	101.8	118.6	79.1	51.5	74.7	64.4	93.3	112.6	75.2	61.6	56.4	53.4	78.5
1963 - 1964	97.0	112.4	88.2	55.5	51.3	45.9	111.1	101.8	126.1	89.9	75.0	59.4	84.5
1964 - 1965	112.3	103.0	92.0	84.0	51.7	42.7	76.4	83.7	40.2	31.8	39.0	60.7	68.1
1965 - 1966	98.9	119.4	78.9	57.5	44.2	50.6	73.2	112.1	106.8	73.5	87.1	64.4	80.5
1966 - 1967	100.1	129.6	126.9	57.5	75.4	60.9	58.1	86.9	80.4	58.5	52.2	53.3	78.3
AVERAGE	114.3	130.2	106.4	76.4	64.0	59.0	87.7	111.7	94.6	67.1	57.7	59.3	85.7

* INDICATES 39 MONTH DRY PERIOD MARCH 1956 THROUGH MAY 1959. AVERAGE FLOW 69.5 M^3/SEC.

o MINIMUM CONTINUOUS 12 MONTH DRY PERIOD APRIL 1957 THROUGH MARCH 1958. AVERAGE FLOW 62.8 M^3/SEC.

Robert Allen Nov. 2. 1968

MONTHLY PEAK FLOWS – RIO ANCHICAYA – CAUDALES MAXIMOS MENSUALES

AÑO	ENERO	FEBRERO	MARZO	ABRIL	MAYO	JUNIO	JULIO	AGOSTO	SEPTIEMBRE	OCTUBRE	NOVIEMBRE	DICIEMBRE
1949			313	422	795	600	254	383	180	1020		
1950			396	518	473	533	216	225	545	350	1060	700
1951	250	210	396	365	330	521	293	283	358	498	240	352
1952	365	256	347	448	460	355	372	191	198	611	727	518
1953	374	203	285	391	687	500	205	145	492	473	445	427
1954	367	281	308	739	367	417	208	136	347	495	690	417
1955	365	367	539	657	878	432	473	442	661	1183	680	385
1956	418	468	422	486	638	533	238	212	221	352	389	435
1957	195	173	268	369	386	461	130	102	144	369	561	357
1958	218	91	115	629	645	212	173	236	191	765	1089	404
1959	207	141	150	415	584	887	178	415	327	738	599	513
1960	645	376	847	887	567	281	288	446	352	728	415	1290
1961	338	176	494	552	313	448	494	137	187	422	645	581
1962	268	432	443	593	620	334	313	525	525	461	1146	404
1963	175	290	304	728	638	277	286	173	191	467	446	473
1964	292	313	302	491	430	470	295	476	151	638	489	295
1965	430	238	220	309	306	144	107	327	306	394	973	348
1966	357	180	435	904	533	608	246	587	272	464	386	391
1967	246	268	302	270	338	299	338	195	288	542	641	
1968												
CAUDAL MAXIMO MAXIMUM PEAK RECORDED	645	468	847	904	878	887	494	587	661	1183	1146	1290

RNA.