PROGRAM FOR SEDIMENT INVESTIGATIONS THJORSA AND HVITA RIVERS, ICELAND

By
V. A. Koelzer

HARZA ENGINEERING COMPANY INTERNATIONAL

Reykjavík, Iceland September 2. 1961

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SUMMARY OF PROPOSED PROGRAM FOR SEDIMENT INVESTIGATIONS THJORSA AND HVITA RIVERS, ICELAND

In accordance with the request of the State Electricity Authority I have made a reconnaissance of the lower Thjorsa-Hvita river system, studied the available data and considered the sedimentation problem in relation to the four most likely initial projects, (Burfell, Urridafoss, Hestvatn and one in the Hvitarvatn area).

The investigations I have made lead me to the belief that, while sediment problems exist which require serious consideration and investigation, the problems can be adequately solved by relatively standard engineering investigations. The sedimentation problems are not of sufficient magnitude to hold up detailed planning of any of the potential initial projects, and should not be allowed to delay negotiations for their development. The sedimentation problems are less serious than in many other areas of the world where projects have been successfully constructed and operated.

The following recommendations are made;

A. Collection of basic data

(1) Collect a sufficient number of samples to define the discharge - suspended sediment load relationship at the following locations:

Thjorsa at Trollkonuhlaup gaging station
Thjorsa at Urridafoss gaging station
Hvita at Hvitarvatn Bridge
Jokulfall near mouth
Hvita at Bruarhlod Bridge

Hvita at Ida
Bruara at Bridge near mouth (limited sampling only)

(2) Make three discharge measurements by boat (low, medium and high flows) on Hvita above Bruara confluence and Thjorsa below Urridafoss, with special bed material, suspended load and slope measurements.

B. Computations

(1) Compute average suspended load at 6 locations of intensive suspended sampling listed in A (1).

(2) Compute bed-load on Hvita and Thjorsa, utilizing data collected in A (2).

(3) Compute sediment deposition in reservoirs.

(4) Make backwater and regime channel computations for Hestvatn, Urridafoss, Burfell and Hvitarvatn Projects.

C. Equipment and installation

(1) Purchase two additional depth-integrating sediment samplers (D-43 type) (Cost at $255 each = $510)

(2) Purchase three additional hand operated sediment samplers (DH-48 type) (Cost at $40 each = $120)

(3) Purchase three reels for raising meters and samplers (Cost at approximately $100 each = $300)

(4) Manufacture one portable bridge crane and two sounding weights (kronur expenditure)

(5) Install two cableways, over Thjorsa at Trollkonuhlaup and over Jokulfall near its mouth. (kronur expenditure)

(6) Install water stage recorder on Jokulfall (Cost = $450 for instruments plus kronur expenditure for installation)

(7) Install stream flow station with staff gage on Hvita at Ida (kronur expenditure)

The total foreign exchange expenditure would thus be about $1400, not including shipping costs and materials for cableways. I have not attempted to estimate kronur expenditures, as these can be better estimated by the staff of the State Electricity Authority.

The above program is designed for accomplishment by next summer, using personnel presently available. The program is planned to allow integration into the program recommended by Mr. Donley. It is purposely held to a minimum to be within the resources of the State Electricity Authority. At the same time I believe the data, if obtained, will be adequate for the sediment investigations required for detailed planning of the project.

The attached report includes a discussion of the sedimentation problems anticipated and possible solutions, details of the recommended data collection program, the required equipment and installations, and the method of computations, and general comments on related hydrologic matters.

Very truly yours,

V A Koelzer

V. A. Koelzer

DETAILED REPORT

PROPOSED PROGRAM
FOR SEDIMENT INVESTIGATIONS
THJORSA AND HVITA RIVERS, ICELAND

CONTENTS

CHRONOLOGY OF INVESTIGATIONS AND DISCUSSIONS

I arrived in Reykjavik on August 22 and spent a portion of that day with Mr. Tomasson. The following day included a review of the sediment data available in the office of State Electricty Authority and the estimates of bed-load on the Hvita by Mr. Tomasson. A luncheon meeting with Messrs. Gislason, Briem, Thoroddsen, Thorlaksson, Snaevarr, Tomasson and Jonsson was also held. The following day was spent with Messrs. Tomasson and Jonsson in the field, inspecting the Hestvatn Project, and observing gaging stations and river crossings on the Hvita, Sog, Bruara and Tungufljot, between Hestvatn and Gullfoss.

August 24 was spent in computations of bed-load on the Hvita, and, following Mr. Willey's arrival, in discussions with Mr. Briem. On August 25 I accompanied Mr. Willey to a meeting with Mr. Thoroddsen, concerning his investigations on Hvita system projects. Later I attended a meeting with Mr. Gislason and Mr. Tomasson on general aspects of the proposed sedimentation investigations. The substance of these meetings was that the investigations should be centered about the four most likely initial projects, namely, Hestvatn, one of the Hvitarvatn projects, Urridafoss and Burfell.

Following office discussions and preparations on August 28, I accompanied Mr. Jonsson to the Thjorsa, where the river was inspected on August 29, from Urridafoss to the Burfell area. A coastal glacial stream, the Markarfljot, which originates from the glacier Myrdalsjokull, was also visited. The east bank of the Hvita opposite the Hestvatn Project was visited on the same day. The following day I accompanied Mr. Tomasson to the Hvitarvatn area, after which we returned to Reykjavik, viewing the Stora-Laxa en route. The remainder of my visit, prior to departure on September 2, was spent in preparation of this report, discussions with Mr. Rist and Mr. Tomasson, and presentation of recommendations to Mr. Briem.

SEDIMENT PROBLEMS AND POSSIBLE SOLUTIONS

General

A comparison between estimated loads in Iceland and streams in the U.S. is shown on Table 1. The comparisons in Table 1 indicate that, relative to most U.S. streams, the sediment load in Iceland, when considered in terms of sediment concentration (milligrams of sediment per liter of water) is very low. This is true even when compared to streams which are considered in the U.S. as not presenting sediment problems, such as those in the TVA system. The total sediment load, in terms of millions of cubic meters transported annually, is fairly large. However, the large water discharge of the rivers gives a large sediment carrying capacity which tends to minimize the problems that may be created. Nevertheless, due to the relatively large volume of sediment in transport, aggradation problems will probably arise in the small reservoirs behind diversion structures or initial low dams. This aggradation can and must be adequately considered by proper design of the structures, canals and other project features.

My visit in Iceland was too limited in duration to arrive at any definite conclusion as to the sources of the sediments carried in the Iceland streams. Certainly the glaciers have contributed a major portion - practically all of the finer suspended sediments and perhaps much of the coarser material transported as bedload. In the areas visited I noted that moderately heavy rain showers resulted in runoff which carried practically no silt loads - in fact the smallest watercourses were practically clear. This would be expected in the areas visited, as the overlying soils have been almost completely carried away by wind or water erosion, leaving only a denuded rocky surface. The possibility exists that the material carried away from its original location by wind erosion has been deposited in locations (aided possibly by water transport) where it can be carried away as bedload.

In any event, while academically interesting, knowledge of the specific source of the sediments is not essential at this time. The most important fact is that we know that substantial sediment loads exist. The immediate problems are to obtain reasonable estimates of the magnitude of the sediment load and to develop project designs which eliminate or mitigate the adverse effects of the sediment load.

The Thjorsa and Hvita Rivers undoubtedly carry a high percentage of bed-load relative to suspended load. This does not mean that the total load is abnormally high - in fact, the bed-load is a high percentage of the total load only because the suspended load is so small. The milky appearance of the glacial streams creates a misconception of heavy load - particularly when considered in relation to the spring-fed streams of Iceland, which are practically clear.

A bed-load equal in magnitude to suspended load would classify the Iceland streams as having one of the highest bed-load percentages in the world. The highest bed-load stream of which I have knowledge is the Loup River in Nebraska, U. S. A. There the bed-load percentage has been measured to about 96 percent of the suspended load. I would not be surprised if the bed-load in the Thjorsa-Hvita system was as high as 100 percent of suspended load. Nevertheless, the resulting volume of bed-load would be small in relation to the carrying capacity of the river.

In the following paragraphs specific problems for each potential project are discussed, together with possible solutions.

Hestvatn Project

An estimate of the suspended sediment load of the Hvita at the proposed diversion dam have been made by Rist in "Hydrologic Report - Hestvatn Hydroelectric Project," originally Febr. dated July 1961. He estimated the annual sediment load to be about 500, 000 cubic meters, based on an estimate for the Hvita at Gulfoss. I have made an independent estimate of about 570, 000 cubic meters for the Hvita at

Gulfoss. I believe the Gulfoss load is practically equal to that at Hestvatn. The close agreement is not surprising since the same sediment and flow data were used and the methods used were not greatly different. However, we cannot assume that the estimate is highly reliable - the sediment data is too limited in scope and the results must be considered to be of limited accuracy.

Mr. Tomasson, in a report entitled "Development of Hvita at Hestvatn - Sedimentation" dated June, 1961, estimated the annual bed-load transport above the Bruara confluence to be 405,000 cubic meters. His estimate for the reach below the Bruara confluence was 500,000 cubic meters. Tomasson used the Einstein approach, as modified by Rouse. I made an independent estimate, using the Schoklitsch formula, and obtained an estimate of 575,000 cubic meters for the river above the Bruara confluence. The data available for application of bed-load formulas was of lesser reliability than for the suspended load calculations, so that the results of the bed-load computations are in considerable doubt.

Addition of the suspended and bed-load estimates would result in a total load of about one million cubic meters per year. There is some doubt that the two should be added directly. The Gulfoss station is at a location where considerable turbulence exists and, therefore, a higher percentage of transported material should be in suspension than at Hestvatn. On the other hand, the Gulfoss station is at a location above the Stora-Laxa, which may contribute a minor amount of sediment, and measurements at Gulfoss were taken by dipping a sample at the water's edge, which would tend toward underestimation of the sediment concentrations. When these counteracting factors are considered, I would judge that direct addition is justified, and that a value of about one million cubic meters of annual total load is a reasonable approximation with the limited data available.

The above estimate of total load, while admittedly of doubtful reliability indicates that the annual load is large in relation to the volume of the reservoir above Hestvatn (estimated by Harza to be about five million cubic meters below the diversion canal and seven million cubic meters above the canal). While most of the suspended sediment and some of the bed-load will undoubtedly pass through the reservoir, appreciable quantities may deposit and cause aggradation of the river channel above the diversion canal unless corrective measures are taken. This aggradation could cause flooding of adjacent farm areas during medium stages, in contrast to natural conditions where flooding occurs only at high stages.

Several alternatives are possible with respect to the aggradation problem in Hestvatn, as follows:

(a) Take no corrective measures, on the assumption that, since the farms are currently flooded during high stages and are used only for grazing or hay production, no additional damage will result from the additional flooding that could arise at medium stages. This might be called a "wait-and-see" approach, in which a calculated risk is taken of possible damage and damage suits, with the actual damage being determined after the project is in operation.

(b) Purchase the potentially flooded land, possibly to be rented to the farmers, with the farmer assuming the risk of flooding.

(c) Obtain flowage easements on the potentially flooded land. In this case the farmer would retain ownership but would be paid for the right by State Electricity Authority to flood his land. The farmer would continue to use the land but would assume all risks involved.

(d) Construct a levee or levees to confine the reservoir area at all stages to the present limits of the river channel.

(e) Construct groins or other corrective works which would confine the major discharge to a limited area in the present river channel. In effect, this would be canalizing a reach of the reservoir. With proper design, concentration of discharge would provide sufficient sediment transporting ability to prevent aggradation.

The selection of a method to be used would depend upon more reliable estimates of the sediment load and further design studies, and also upon economic comparison and political considerations. I have no doubt that the alternatives presented would yield a satisfactory solution which would not seriously affect the overall economics of the project.

The diversion channel between the Hvita and Hestvatn should be designed as a regime canal, that is, a canal that would neither degrade or aggrade over a period of time. Such canals have been designed successfully in the Punjab area of West Pakistan, to carry water much higher in sediment content than that of the Hvita, for a distance of 30 to 50 kilometers. Therefore, I would invisage no difficulty in designing a stable channel for this one-kilometer reach. Specific design features must await the obtaining of additional sedimentation data.

The capacity of Hestvatn is estimated to be 161 million cubic meters. Even if the annual sediment load of the Hvita is substantially larger than the one million cubic meters estimated and all of the sediment were to be transported to Hestvatn, the useful capacity of the reservoirs would not be endangered for over 100 years. Actually, of course, much of the sediment will be carried past the diversion dam. Also, construction of storage projects upstream, which would trap a portion of the sediment load, can be anticipated in the future. Thus the filling of Hestvatn does not appear to be a problem.

I will consult with our engineers who are working on the Punjab developments to obtain a preliminary estimate of the cross-section required for the diversion canal and any corrective features that may appear applicable. This will be included in our review comments on the Hestvatn Project, for use in current preliminary cost estimates.

Hvitarvatn Projects

The alternative developments that have been proposed for the Hvitarvatn area all involve construction of a dam over the Jokulfall River to divert the Jokulfall to Hvitarvatn. The sediment entering the Hvita from Hvitarvatn appears to be extremely fine, with little bed-load, and probably presents no serious problem. The Jokulfall appears to carry more suspended load, with appreciable bed-load.

The small reservoir created in the present Jokulfall river channel would probably fill with sediment in a relatively few years. No problems due to aggradation upstream appear likely, as the contiguous areas do not serve agricultural or other purposes. Eventually, with the filling of the Jokulfall channel, the natural diversion channel between the Jokulfall and Hvitarvatn might aggrade. Permanent blocking of the diversion channel is not anticipated.

The channel would eventually assume regime conditions, adapting itself to the section and gradient necessary to maintain stable conditions. This will probably require that the elevation of the top of dam on the Jokulfall be somewhat higher than the top of dam on the Hvita. Routine hydraulic and sedimentation calculations are necessary for detailed planning purposes. The completion of these calculations as a basis for design should await the obtaining of additional data on the Jokulfall flows and sediment load.

Urridafoss Project

The problems at Urridafoss appear to closely parallel those at Hestvatn. Aggradation of the river channel upstream is likely unless corrective measures are taken, with possible flooding of adjacent farm lands. The possible solutions are the same as listed for the Hestvatn Project.

Burfell Project

The initial Burfell Project may involve construction of a low dam, or sill, about 1.5 kilometers upstream of Trollkonuhlaup, which would raise the water level several meters. Ultimately, a dam about 0.5 kilometers upstream from the falls would raise the water level to elevation 240 to 260 meters. At either of these latter elevations, an auxiliary dam will be needed at Rauda Gap, approximately 8 kilometers upstream from the main dam.

For the initial development, sluices should be provided in the low dam to allow the sediment load of the stream to pass. The intakes to the power tunnel should be located some distance above the stream bed, to exclude the heavier bed-load from the tunnel. The finer sediments carried in suspension would be of such low concentration and size that damage to the turbine runners would not result. Some aggradation of the stream-bed upstream of the low dam could occur, although this appears unlikely in view of the rather high gradient of the stream and the resulting high sediment transporting capacity of the stream, during occurrence of flows in excess of turbine capacity. If such deposition should occur it could cause difficulties in excluding bed-load from the power tunnel. A rise in water level sufficient to spill water during high flows to the Ytri-Ranga River, to the left of the Thjorsa, is also a remote possibility. Some investigation of these possibilities, which require additional sediment data, is desirable.

Ultimately, much of the sediment load of the Thjorsa will be deposited behind the higher dam. Exclusion of sediment from the power tunnel can be accomplished by provision of sluices in the dam and redesign of the power tunnel intakes. Aggradation of the river channel upstream will cause the water surface elevation at the Rauda Gap to be higher than under backwater conditions prior to sedimentation. Estimates of the sediment load and backwater after sedimentation will be necessary to establish the elevation of the auxiliary dam at Rauda Gap. This is a routine design computation, but it will require the collection of data on the sediment load of the Thjorsa.

RECOMMENDED DATA COLLECTION

Observations at selected locations

The sampling program is specifically designed to meet the planning needs of the four possible initial projects - Hestvatn, one in the Hvitarvatn area, Burfell, and Urridafoss. The program is planned to agree as much as possible with the stream gaging program recommended by Mr. Donley. Additional sampling will undoubtedly be required for planning of other projects in the Thjorsa-Hvita system, but such sampling is not included in the present program because budgeting and personnel limitations necessitate that the work be limited to that essential for initial planning. However, the data collection recommended will fit into any long-range program of sampling that may ultimately be involved.

The following paragraphs describe the sampling recommended at specific locations. Detailed methods of sampling and analysis and a listing of the equipment necessary are given in a later section.

Jokulfall near its mouth - A D-43 depth-integrated sample should be taken at the time of each discharge measurement. In addition, a hydrographer should be stationed in the Hvitarvatn area for about six weeks during the highwater period of April-May on the Jokulfall.

During this time a D-43 depth-integrated sample should be collected twice daily. A simple field laboratory could be established during this period to analyze the sample for concentration, to reduce the problem of transportation of samples. This would consist of equipment to evaporate a decanted sample, with volumetric measurement of the water in each sample. The dried sample would be retained in a suitable paper container for determination in Reykjavik of its weight. A limited number of samples should be retained for size analyses.

If the hydrographer stationed for the six week period is trained for such measurements, and if time permits, three special measurements could be taken at a suitable location above the gage for computation of bed-load. This is of secondary importance to other works, and should be done only if it can be performed by the hydrographer resident at Hvitarvatn. It is not of sufficient importance to merit special observations by someone traveling to the area from Reykjavik.

<u>Hvita at Hvitarvatn Bridge</u> - Sampling at this station would be accomplished by the hydrographer stationed at Hvitarvatn, in the same manner as on the Jokulfall. Samples would also be taken at the time of each discharge measurement.

Hvita at Bruarhlod - Approximately 10 samples should be collected with a D-43 sampler. It is possible that the entire depth cannot be sampled, but an additional weight suspended below the sampler might be of assistance. If a reasonable portion of the depth cannot be sampled, these observations should be abandoned, as the entire purpose is to collect samples in a constricted section where all of the material is believed to be in suspension, and the value of the samples would be largely lost if most of the depth cannot be sampled.

If the D-43 samples are successful, about 40 DH-48 samples should be taken by a local observer.

Hvita at Ida - This is the most important station on the Hvita. Approximately 20 depth - integrated samples should be taken with the D-43 sampler, supplemented by about 80 samples taken by a local observer with a DH-48 sampler. Sufficient discharge measurements should be made to adequately define the stage-discharge relationship and daily or twice daily stage observations should be obtained.

Bruara at Bridge near mouth of Bruara - The sole purpose of this station is to establish with actual data that the sediment load of the Bruara is negligible. About 5 random samples with a D-43 sampler will suffice for this purpose.

Hvita above Bruara - Three special measurements should be taken in a reach above the Bruara, where the reach is in alluvial material and is of reasonable uniformity. The purpose of these measurements is to allow the computation of bed-load. The data collected during these measurements should include the following:

(a) A regular discharge measurement, involving 25 to 30 vertical sections across the river (0.2 and 0.8 method satisfactory)

(b) Four depth-integrated samples, one in the main channel, one in the west channel, and two in the "sand bank" section.

(c) Total concentration in mg/l and size analysis of the three depth-integrated samples, each sample analyzed individually for concentration, but combined for size analysis if a sufficient volume of sediment is not available for size analysis to analyze the samples individually.

(d) Depth of the stream at the location of the suspended sediment sample.

(e) Size analysis of the bed material, taking the average of about five bed samples collected at the time of the sampling.

(f) Water temperature

(g) Slope of water surface, determined by leveling to an accuracy of .00005, if possible.

The three special sediment measurements should be taken to cover a range of flows. One should be taken at medium low flow (about 250 Kl/s), one at medium flow (about 450-500 Kl/s) and one at as high a flow as possible (above 750 Kl/s).

Thjorsa at Trollkonuhlaup - Suspended sediment samples should be collected at a cableway to be installed at the existing water stage recorder location. The turbulent flow at this location will make it difficult to lower a meter to the full depth but as much of the vertical section should be sampled as possible, since a satisfactory alternative does not exist. A sample should be taken at the time of each discharge measurement, utilizing the D-43 sampler. During a 6-weeks period of April or May, samples with a D-43 sampler should be taken daily by the drilling crew which is expected to be in operation at that time. This should provide about 50 samples, which is considered the minimum acceptable for a reasonable analysis of the sediment load of the stream. Subsequently, if additional personnel are located at the damsite, sampling should be continued.

Thjorsa at Urridafoss - Samples should be collected with a D-43 sampler at the time of each discharge measurement. Additional samples should be collected at the highway bridge with the D-43 sampler on about 10 other occasions, when discharge measurements are not contemplated. These should be supplemented by about 80 "dipped" samples, collected with a DH-48 sampler by a local observer, at a convenient location below the falls.

Three special-type sediment measurements should be taken at the regular discharge measurement section, for computation of bed-load. The data collected should be the same as for the Hvita above Bruara, except that only three depth-integrated samples will be needed, at approximately 1/4, 1/2 and 3/4 of the distance across the river.

Method of sampling and analysis -

A D-43 sample should consist of three depth integrations, one each at approximately the 1/4, 1/2 and 3/4 points across the river. The samples should be taken at times that would adequately cover the discharge range throughout a yearly cycle, with particular effort to obtain measurements at high flows. If DH-48 samples are also being taken regularly at the same station by a local observer, a DH-48 sample should be taken at the time of each D-43 sample, using the same method and location as the local observer, to allow correlation between the two methods.

All three depth-integrations should be combined for concentration and size analysis, except for the special measurements at Urridafoss and the Hvita above the Bruara. About 10 of the D-43 samples should be analyzed for particle size at each station.

The method of sampling with the DH-48 sampler will vary with each location. These samples will be taken by local observers and therefore must be taken from the banks, since the hand equipment will be all that the observer has. The sample should be collected throughout a range of depth, if conditions permit. Alternatively, the sampler can be moved diagonally through both a horizontal and vertical range. If neither method is possible the sampler can be allowed to fill slowly while holding it substantially at the same point. Samples should be collected weekly at Ida and Urridafoss, and semi-weekly at Bruarhlod, with emphasis being given to obtaining additional samples at high stages.

It is most important that gage heights be observed at the time of each sample, whether it be by a hydrographer or by a local observer, to allow determination of discharge. Without a determination of discharge, the sediment sample is virtually worthless.

Equipment and installations required

The following equipment and installations will be needed:

1. Total of 3 D-43 samplers with hangers and pins (2 additional), for use as follows:
   (a) One with mobile stream-gaging crew
   (b) One to be stationed at Hvitarvatn during April-May, at other times to be used in mobile operations
   (c) One to be stationed at Trollkonuhlaup during April-May, at other times to be used in mobile operations
2. Total of 4 DH-48 samplers (3 additional), for use as follows:
   (a) One with local observer at Bruarhlod
   (b) One with local observer at Ida
   (c) One with local observer at Urridafoss

(d) One with mobile stream gaging crew

3. One bridge crane, type A with 4 wheel truck (see page 204 of Water Supply, Paper 888), for use at Bruarhlod and Ida, drawings to be sent from Chicago for manufacture in Reykjavik.

4. Two 75 lb. sounding weights, drawings to be sent from Chicago for manufacture in Reykjavik.

5. Three type B USGS type reels (see page 205 of Water Supply Paper 888), to be used as follows:

   (a) with mobile crew, for use with bridge crane

   (b) At Hvitarvatn

   (c) At Trollkonuhlaup

   If funds are too limited, the reels for the Hvitarvatn and Trollkonuhlaup cableways could be eliminated, with sediment samples taken by manually raising and lowering the sampler. This is somewhat difficult but not impossible.

6. Two cableways, with "stand-up" type cars (plate 23 of US Geological Survey Circular 17), located at:

   (a) Jokulfall

   (b) Trollkonuhlaup

7. Installation of a water stage recorder at Jokulfall

8. Installation of a staff gage at Ida

Our recommendation for gaging stations in the Hvitarvatn area differs from Mr. Donley's recommendations. He recommends a station on the Hvita below the confluence with the Jokulfall, to supplement the existing station on the Hvita above the confluence. We believe it would be preferable to have a gage on both the Hvita above the confluence and on the Jokulfall, which would eliminate the need for a station below the confluence. Our reasons are (a) better access, (b) shorter cableway, and (c) the desirability of determining the sediment load and water discharge of the Jokulfall directly, rather than by subtraction of the Hvita above the confluence from the Hvita below the confluence.

COMPUTATIONS

The computations cannot be completed until the sediment data described in the preceding section have been collected. Only very preliminary calculations can be made at this time. However, a description of the methods anticipated will be useful, since a knowledge of its ultimate use will aid in the data collection program. The methods described represent the calculations anticipated at this time - some changes will undoubtedly occur as the computations evolve.

Hestvatn Project

The general procedure proposed is to (1) compute the suspended load, (2) compute the total load, (3) compute backwater curves under existing undeveloped conditions, (4) compute suspended and bed-load deposition in reservoir for various periods after construction and (5) compute backwater curves after degradation. The computations can be carried out for various assumptions of normal water surface elevation at the dam and for various assumptions of corrective works, as needed.

Computations of suspended load should be made by first developing a curve for the Ida station relating water-discharge to sediment load. Log-log plotting is desirable for this purpose. This is then combined with the flow duration curve to estimate annual suspended load. The method used by Rist is satisfactory for this purpose. A slightly different format, which differs only in technique rather than in principle, is described in a paper by Schroeder and Maddock. A copy of this report was left with Mr. Tomasson. Either method is satisfactory.

I recommend that total load be computed by the modified Einstein method, described in US Geological Survey Water Supply Paper 1476, a copy of which is in Mr. Rist's files. This would utilize the three special measurements recommended to be taken on the Hvita above the Bruara. Check computations should be made with other methods, such as the Rouse modification of Einstein's method, or the Schoblitsch equation. Computations will need to be made for a range of discharges in the same manner as calculated by Mr. Tomasson for this section, to develop a relationship between discharge and load. The computation of annual load can be made either by the method used by Rist and Tomasson or by the Schroeder-Maddock method.

If the sampling at Bruarhlod is successful, the results can probably be considered equivalent to total load, and the total load can be computed the same procedure as indicated for the suspended load at Ida. A comparison with the computations at Hestvatn would give a check on the Hestvatn computations, with appropriate allowance for the estimated sediment inflow from the Tungulfljot. and Stora-Laxa.

Natural backwater curves have been computed by Mr. Engebretsen of our Chicago office. Copies of these computations have been furnished to Mr. Tomasson and can be used as a pattern for any revisions that may be necessary.

Deposition of suspended load in the reservoir probably can be computed from the curves of trap efficiency for TVA reservoirs presented in the paper by M. A. Churchill, a copy of which was left with Mr. Tomasson. This will involve separation into various flows, utilizing flow duration curves in much the same manner as for the computation of sediment inflow. A sample copy of computations has been left with Mr. Tomasson. The computed deposition can be divided between two sections of the reservoir, above and below the diversion canal, and will result in estimates of the suspended load transported to Hestvatn and to the river below the diversion dam.

The Churchill curves are for data ending about 1942. It is probable that a considerable amount of data has since been accumulated by TVA. Use of these curves assumes that the particle size of the Hvita sediment is about the same as that in the TVA, reservoirs. Churchill does not present data to verify this. Further, there is some doubt as to the units in the Churchill curve. I will write to Mr. Churchill to verify these points. and to obtain the latest curves.

The method described will give an estimate of the suspended sediment deposition during the first year after completion of the project works. Deposition of bed-load in the first year can be neglected, since the river is assumed to be regime originally. Backwater curves can then be computed under aggraded conditions for the first year. In the second year the deposition will be somewhat less, due to the reduced volume of the reservoir and consequent reduction in trap efficiency. The amount of suspended load deposited in the second year can be computed in the same manner as for the first year. Bed-load deposition can be computed by computing bed-load transport by a suitable formula and comparing the bed-load transported under aggraded conditions with the bed-load prior to aggradation. This process can be carried to a point of time until regime conditions are established, i.e., until there is no appreciable deposition in the reservoir reach.

The above procedure can be applied for different reservoir levels, or to establish a reservoir level that will result in insignificant flooding of adjacent lands. If a canalized section of the main river is to be considered, essentially the same procedure can be used. For this case, we will furnish criteria for estimation of the required channel section to establish regime conditions.

As indicated, the computation procedure as currently visualized may need revision as the computations evolve. We will furnish consultation, review or advice as needed in this process, if so requested.

Hvitarvatn Projects

Estimates of suspended sediment load can be computed by the method described for the Hvita at Ida. If the special measurements on the Jokulfall are not taken, bed-load can be estimated with sufficient accuracy by using the percentage of suspended load computed at

Hestvatn. The distribution of sediment in the reservoirs can be estimated by the procedure in the Bureau of Reclamation publication entitled" Interim Report on Distribution of Sediment in Reservoirs", a copy of which will be furnished from Chicago.

Urridafoss Project

Computations here would be almost identical to those for Hestvatn and can follow the same general pattern.

Burfell Project

Estimates of suspended sediment load at the sampling station should be equivalent to the total load upstream of the falls because of the high turbulence which should cause all material to be in suspension. These estimates would be made by the same method as for the Hvita at Ida. The deposition of sediments can be computed from the TVA curve described for the Hestvatn computations and the distribution of sediment by the procedure described for the Jokulfall Reservoir. Backwater computations can be made as described for Hestvatn.

RELATED HYDROLOGIC OBSERVATIONS

While review of the streamgaging program was not within my assignment, a review of Mr. Donley's report and observations of the operations of the Hydrologic Survey has led to some general conclusions regarding the stream gaging program that may be of interest. While we might disagree with Mr. Donley on certain details, we are in essential agreement with his overall recommendations. As he has stated, the large scale power development program envisaged demands a long range program of basic hydrologic data, the scope of which appears impossible of accomplishment without substantial expansion of the limited existing facilities of the Hydrologic Survey.

The heavy demands placed on your current organization require the maximum streamlining of procedures. In this connection I strongly urge that you follow Mr. Donley's recommendation to abandon the practice of making complete vertical velocity observations, and adopt in lieu thereof the "0, 2 and 0, 8" method he recommends. This procedure has been so well proven by the operation of over 7000 gaging stations in the U.S., covering a wide range of conditions, that it can be adopted with assurance there will be no significant loss of accuracy. Adoption of this method will save significant time in field measurements and in processing of records.

It is also suggested that you give consideration to the use of a bubbler-type gage. This gage is particularly advantageous in streams where problems of clogging of the intakes are common. It also reduces construction costs, by elimination of costly gage wells, in those streams where a large range in stage is anticipated. However, since it does involve more costly equipment and therefore more foreign exchange, I am making this a suggestion for consideration rather than as a firm recommendation. The desirability of using a bubbler gage can only be decided by you after consideration of all the economic factors involved. I have agreed to furnish Mr. Rist with information on the bubbler gage.

V. A. Koelzer

TABLE 1.

COMPARISON OF SEDIMENT LOAD IN HVITA WITH U.S. STREAMS

Stream	Drainage area (sq.km.)	Annual Discharge (M^3x 10^6)	Annual Sediment Load (M^3x10^3)	Annual Sediment Load (M^3/sqkm)	Annual Sediment Load (Mg/l)
Hvita	4,360	8,300	1,000	230	150
Problem streams in U.S.					
Arkansas at Pueblo, Colorado	12,200	660	930	76	1,700
Smoky Hill nr. Ellis, Kansas	13,000	94	330	25	3,650
Middle Loup nr. Dunning, Nebraska	200	340	380	1,900	1,500
S.Loup at St.Michael, Nebraska	4,300	355	2,200	510	7,000
N.Loup at St.Paul, Nebraska	3,400	890	2,300	680	2,900
Powder at Morehead, North Dakota	21,000	440	10,000	480	24,700
Niobrara at Cody, Nebraska	1,000±	410	500	500	1,300
Moreau at Bixby, South Dakota	4,100	154	1,300	320	9,000
Cheyenne at Angostura, South Dakota	23,500	960	9,300	400	10,300
Grand at Wakpala, South Dakota	14,100	278	1,280	91	4,900
Heart at Mandan, North Dakota	8,700	253	2,160	250	10,200
Big Horn at Thermopolis, Wyoming	21,000	1,660	6,900	340	4,400
N.Fk.Red at Altus, Oklahoma	6,600	160	1,310	200	9,200
Pecos at Artesia, New Mexico	25,000	350	1,640	78	6,400
Rio Puerco at Rio Puerco, N. Mex.	15,100	59	14,400	950	244,000
Rio Jemez nr. Jemez, New Mexico	2,600	62	3,760	1,440	61,000
Rio Chama nr. Chamita, New Mexico	8,300	540	7,300	880	13,500
Rio Grande at Bernardo, N. Mex.	43,000	1,230	7,400	170	6,000
San Juan at Bluff, Utah	60,000	2,700	34,000	570	14,200
Colorado at Lees Ferry, Arizona	280,000	16,800	145,000	540	9,600
Paria at Lees Ferry, Arizona	3,900±	27	5,700	1,500	218,000
Moenkapi Wash at Tuba, Arizona	3,500±	18	1,410	400	80,000
Non-problem streams in U.S.					
Story Cr.-Stony Gorge Res., Cal.	505	220	48	95	225
Boise River-Arrowrock Res., Idaho	5,300	1,000	295	58	300
Osage at Eldon, Missouri	36,000	9,000	7,900	220	860
Holston at Cherokee Dam (TVA)	8,700	3,800	1,010	115	240
French Broad at Douglas Dam (TVA)	6,700	5,900	3,000	450	495
Clinch at Norris Dam (TVA)	7,300	3,300	1,300	180	352
L.Tennessee at Fontana Dam (TVA)	4,000	3,700	730	180	175