Report On

BULL RUN STORAGE DAM NO. 2 AND HYDROELECTRIC POWER FACILITIES BULL RUN RIVER FOR CITY OF PORTLAND, OREGON

CITY COUNCIL

Terry D. Schrunk, Mayor

Ormond R. Bean, ... Commissioner of Finance
Nathan A. Boody, ... Commissioner of Public Utilities
William A. Bowes, ... Commissioner of Public Works
Stanley W. Earl, ... Commissioner of Public Affairs

APRIL, 1957

AN ENGINEERING REPORT BY STEVENS & THOMPSON 2234 S. W. FIFTH AVE., PORTLAND, ORE.

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April 1957

By

STEVENS & THOMPSON
2234 S. W. Fifth Avenue
Portland, Oregon

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INVESTIGATIONS • REPORTS • DESIGN AND SUPERVISION OF CONSTRUCTION

1155

April 15, 1957

CLARA C. THEW, EXECUTIVE SECRETARY

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LETTER OF TRANSMITTAL

H. Kenneth Anderson
Chief Engineer
Bureau of Water Works
Portland, Oregon

Dear Mr. Anderson:

In accordance with your instructions and our agreement with the City dated, 24th September 1956, we have made an engineering study to determine the type and cost of a dam to be constructed on Bull Run River to provide additional storage for the water supply. Also, included in our study has been a determination of the hydroelectric power facilities which can be economically developed at the existing and the proposed dams.

Our report on the proposed dam and hydroelectric power facilities is presented herewith. Included as a part of the Appendix are two reports; first is "Preliminary Design of Earth Dam, Lower Bull Run River" by William L. Shannon, Consulting Soils Engineer and the second is "Bull Run Dam No. 2, Geology and Foundations" by Lloyd L. Ruff, Consulting Geologist.

We appreciate this opportunity to be of service to you and the City of Portland.

Respectfully submitted,

STEVENS & THOMPSON

By H. Loren Thompson
H. Loren Thompson

hlt/ct

SUMMARY OF REPORT

General Statement

Bull Run River is known for its excellent water for domestic use, and the available quantity can supply the needs of Portland for many years, provided adequate storage is developed. Several sites for dams to create storage reservoirs are available. The site considered for Bull Run Dam No. 2, immediately above the Headworks, can be developed for additional storage. Present storage is not sufficient under critical water flows which have occurred in the past to assure the City of adequate water for its expanding needs.

Observations and Conclusions

Our observations and conclusions are as follows:

1. A dam can be constructed for the storage of water at the site selected which is some 1200 feet upstream from the Headworks.

2. Certain existing geological conditions will require additional underground explorations during the final design of the work to obtain answers to problems in connection with the spillway location and existing clay layers or lenses under the dam.

3. Storage of approximately 21000 acre feet (6,850,000,000 gallons) can be developed. The exact storage will be determined after logging operations have cleared the reservoir area sufficiently for aerial surveys to be made for topography.

4. Power can be economically developed at Bull Run Dams Nos. 1 and 2, provided the cost of all construction for storage dams is charged to water supply development and provided the power generated can be used as a part of a larger power system.

5. 480 cubic feet per second of water can be delivered to Rosyln Lake, forebay for the Bull Run hydroelectric powerhouse of Portland General Electric Co. during the period October 15 thru June 15 based upon median water. To do this would require the immediate construction of Conduit No. 5 as far as Rosyln Lake. Later, Conduit No. 5 could be extended to the City when needed to meet the summer water demand.

6. 98,000,000 kwhr of electric energy can be generated at the powerhouses proposed for Bull Run Dams Nos. 1 and 2. At 4.5 mills the total annual income would be $441,000 or 11.6% of the capital investment. 64,000,000 kwhr of electric energy can be generated by the 480 cfs which can be delivered to Rosyln Lake.

7. The costs of the various projects outlined are:

Dam, spillway, and intake	$4,350,000
High level intake and connection to Conduit No. 4	526,600
Powerplant at Bull Run Dam No. 1	2,001,000
Powerplant at Bull Run Dam No. 2	1,563,800
Transmission line	233,900
Conduit No. 5 to Rosyln Lake	2,261,500
Total of all projects	$10,936,800

Recommendations

It is recommended that:

1. The City have plans and specifications prepared and construct Bull Run Dam No. 2 and the High Level Intake with its connection to Conduit No. 4.

2. Negotiations be entered into immediately with Portland General Electric Co. for sale of water to Rosyln Lake and for the sale of electric power from the proposed powerplants at Bull Run Dams Nos. 1 and 2. As an alternate, negotiations could be entered into with Pacific Power & Light Co. for the purchase of power and, in that case, the delivery of water to a site at Dodge Park on Sandy River for construction of a power plant there.

3. Upon the conclusion of satisfactory arrangements for the sale of the power, the City proceed with construction of the power facilities including Conduit No. 5 to the extent it is required.

4. The City refer to the people of Portland for approval a general obligation bond issue in the amount of not less than $3,800,000 for power facilities with retirement to be from power revenues.

REPORT ON

BULL RUN STORAGE DAM NO. 2 AND

HYDROELECTRIC POWER FACILITIES

BULL RUN RIVER

FOR

CITY OF PORTLAND, OREGON

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INTRODUCTION

General Statement

Water for Portland comes from Bull Run River. The minimum flow in the river has reached as low as 63 cfs (cubic feet per second) on August 13 - 16, 1926, and the maximum recorded flow was 20,600 cfs, March 31, 1931. The annual mean flow during the water years (October 1 thru September 30) has varied between a low of 457 cfs and a high of 981 cfs since the completion of Bull Run Dam No. 1 (Bear Creek Dam) in 1929. Only in two years of this period has the flow been below 500 cfs, 457 cfs during 1940-1 and 483 cfs during 1943-4. The mean annual flow since 1929 has been 741 cfs.

The lowest summer flow of record was for 1940. The monthly mean flows for the summer of 1940, corrected for storage releases from Lake Ben Morrow, were:

	Flows	
Month	cfs	mgd
June	115	74.2
July	75	48.5
August	59	38.1
September	84	54.3
	Mean	71.7

The peak demand during the summer of 1956 reached 180 mgd (million gallons daily). When full Lake Ben Morrow contains 10,000,000,000 gallons of stored water or equivalent to 83.3 mgd for 120 days. Therefore, together with a mean flow in the stream of 71.7 mgd Lake Ben Morrow could supply an average demand of 155 mgd for the four months of June, July, August, and September should the low flows of 1940 reoccur.

It is obvious that the growth of the City of Portland is such as to demand additional storage to provide an adequate volume of water to the City and the surrounding areas that depend upon Portland for their supply. Therefore, the construction of a second dam to create a storage reservoir is essential to the well being of Portland.

Several storage sites are available on Bull Run River and its tributaries, and it is probable that sufficient storage could be developed to provide for peak summertime demands of some two and one half to three times the present record peak requirements.

Purpose and Scope of Report

The purpose of the investigations covered by this report has been to determine:

1. The type of dam most suited to a site immediately upstream from the water supply intake and headworks facilities.

2. The general construction procedures required in order to provide a continuous supply of water to the City during the construction period.

3. The type of diversion and water intake facilities required behind the dam.

4. The hydroelectric power potentials at the present dam (Bull Run Dam No. 1) and at the proposed dam (Bull Run Dam No. 2).

5. The construction costs for the dam and appurtenant facilities and for the hydroelectric power developments.

Authorization

This engineering study was authorized by the City Council of the City of Portland under a contract dated 24th of September, 1956 under Ordinance No. 104606 passed by the Council on 12th September, 1956.

Acknowledgement

On this important investigation we have had the excellent assistance of Julian Hinds, Consulting Civil Engineer; Lloyd Ruff, Geologist; and William L. Shannon of Shannon and Wilson, Soils Engineers. The cooperation and assistance of H. Kenneth Anderson, Chief Engineer, Bureau of Water Works, City of Portland and his staff have been of great help on this work.

The first exploratory drilling was by Lynch Brothers who did the exploratory drilling for Bull Run Dam No. 1. H. I. Bottner has started some additional exploratory drilling deemed necessary following the original contract completed by Lynch Brothers. This latter work should be completed by the end of May, 1957.

PART I

BULL RUN DAM NO. 2

Historical

A report in 1915 to D. D. Clarke, Chief Engineer, Bureau of Water Works outlined thirteen possible dam sites including that for Bull Run Lake. Dam No. 1 as outlined in the 1915 report was to be located immediately upstream from the Headworks. The estimate of the volume of water to be stored was just under five billion gallons to a normal pool level at elevation 847 having a reservoir surface area of 352 acres.

No dam for storage was constructed until the Bear Creek Dam (referred to in this report as Bull Run Dam No. 1) was built during the 1927-9 period. The 1915 report identified this latter structure as Dam No. 5 with a storage of two and one-quarter billion gallons to elevation 968. It was actually constructed to elevation 1036, and now since completion eight foot spillway gates have been installed, providing a maximum pool level at elevation 1044 with a capacity of just over ten billion gallons or 31,000 acre feet.

Site Location

The selection of the site for Bull Run Dam No. 2 has been based upon three basic criteria: first, volume of storage that can be developed, second, a location that will receive the maximum flow from the drainage area, and third, a site that is readily accessible to existing roads. Only one site exists between the Headworks and the present Bull Run Dam No. 1 which can be used with maximum benefit creating a storage lake to the toe of Bull Run Dam No. 1. This site is approximately 1200 feet above the Headworks. At this point roads exist on both abutments and access for construction is available without the construction of extensive roadwork.

In the 1915 report this site was proposed to be developed as Dam No. 1 with a water surface to elevation 847. To this elevation the 1915 report indicated that the storage reservoir would contain 4,990,000,000 gallons of water with a surface area of 352 acres. This study recommends that the water surface be carried to elevation 860,which will back the water to the toe of the existing Bull Run Dam No. 1. Based on the original survey data for the 1915 report,a dam backing water to elevation 860 would have a capacity of approximately 6,850,000,000 gallons or 21,000 acre feet. This is approximate,but an accurate capacity-head curve will be developed upon completion of logging operations and clearing so that aerial means can be used for obtaining the topography of the reservoir basin.

The axis of the dam will run approximately north and south. The spillway may be a canal type spillway to be located on the south abutment to transport the water around the Headworks facilities. As an alternate to the canal spillway, it is possible to construct a chute spillway discharging directly to the river immediately above the Headworks dam. Certain additional explorations are under way which will be the basis for determining which type of spillway will be constructed.

The general area of the site and its relation to other facilities of the Bureau of Water Works are shown on Plate 1 of the Appendix.

Accessibility

The proposed dam site is located about 33 miles east of the Center of Portland, Approach to the site is by a gravel road which connects to a black-top county road at Bull Run, five miles downstream from the Headworks. A gravel road is maintained by the City and extends to Bull Run Dam No. 1, passing about 1500 feet north of the site of Bull Run Dam No. 2. A gravel branch road leads to the Headworks about 1200 feet west of the site. On the south abutment a forest road extends past the site. Roads to the site made in conjunction with current logging operations connect with the two gravel roads.

Stream Flow and Storage

At the USGS stream gaging station located one mile upstream from the Headworks, the mean annual run-off of Bull Run River during 47 years has been measured as 535,000 acre feet, with a minimum mean annual run-off of record being 330,000 acre feet. The preponderance of this flow occurs during the months of November thru May. Therefore, the addition of 21,000 acre feet of storage to the existing 30,000 acre feet of storage is still such that each reservoir will be full at the beginning of every summer. While the winter inflows are far greater in volume than the available storage, it is possible to develop power facilities to use an economical portion of this excess for power generation. During the summer, the reservoirs would be operated only to release that required to meet the demand of the City of Portland for domestic water.

Plates 4, 5, and 6 show hydrographs of mean daily flow for Bull Run River at the USGS gaging station mentioned above. These cover the years since the construction of Bull Run Dam No. 1, 1929 thru the water year 1952-3.

Bull Run River displays the normal characteristics of streams flowing on the western slopes of the Cascade Range. The main stem is served by many tributaries and, at the dam site under study, it carries run-off from an area of 102 square miles. The drainage basin is well-forested and has steep slopes which vary in elevation from 750 feet to 4770 feet above mean sea level. In winter and spring months much of the basin is covered with snow, but it is nonetheless subject to winter rainfall after the first snow. The average annual precipitation recorded at the Water Bureau's Headworks is 78 inches, and precipitation as high as 137.8 inches and as low as 53.6 inches per year has been observed.

Combinations of the factors ofsteep basin slopes, many tributaries, and winter and summer snow cover subjected to rainfall and large consequent melting of snow provide the situation wherein Bull Run River is subject to floods of considerable magnitude that require from 24 to 36 hours to reach maximum intensities. The average annual flood discharge is 7000 cfs and discharges of 12,500 cfs have a five year frequency of occurrence. The maximum flood of record occurred on March 31, 1931 and attained a discharge of 20,600 cfs, reaching this peak after 7.2 inches of precipitation had fallen at the Headworks in the two days previous to the peak discharge.

The spillway proposed for the dam must pass the anticipated flood from the 102 square miles of drainage area. The contributing area to the spillway at Bull Run Dam No. 1 is 74 square miles. The model tests for the design of the spillway were carried to an equivalent flow of 21,000 cfs or a peak discharge of 290 cfs per square mile. From a study of the recorded flows of various streams in western Oregon and Washington (see Table I) having drainage basins ranging in area from 10 to 1000 square miles, it is considered that a peak discharge of 300 cfs per square mile provides an ample factor of safety for the spillway capacity for Bull Run Dam No. 2. This would provide a peak discharge of 30,600 cfs. The design capacity of the spillway has been set at 30,000 cfs. The difference can more than be taken care of by the discharge capacities of the piping and other facilities through the dam. The recorded peak discharge of 20,600 cfs is equivalent to 202 cfs per square mile of the drainage basin. Therefore, the design capacity of the spillway is 50 per cent greater than the recorded maximum discharge of Bull Run River of the period of record of 47 years.

Proposed Dam

The exploratory drilling indicated that basalt rock was some 80 to 90 feet below the river bed. The great depth to rock and the fact that both

TABLE I

Flood Peak Flows of Streams in Western Oregon and Washington

Cascade Mountains

Stream	Drainage Area at Gaging Station	Peak Flow	cfs/Sq. Mi.
Sandy River	8.7 sq. mi.	650 cfs	75
Blue River	11.5	1630	142
W. Fk. Tilton River	16.4	2460	150
Salmon Creek	18.3	1440	79
Lake Creek	18.8	1600	85
Little Sandy River	22.3	5320	239*
Little Washougal River	23.8	1620	68
Lookout Creek	24.1	3620	150
Luckiamute River	34	5560	164
Gate Creek	47.6	3760	79
Wiley Creek	52	5410	104
Blue River	75	13300	177
W. Fk. Hood River	96	12900	134
Bull Run River	102	20600	202**
Breitenbush River	106	11600	109
Washougal River	108	17600	163
Salmon Creek	117	8040	75
Clackamas River	126	5000	40
Clackamas River	136	6750	50
S. Santiam River	174	23400	135
Fall Creek	186	22500	121
N. Santiam River	216	20300	96
N. Fk. of M. F. Willamette River	246	17000	69
Sandy River	262	29200	111
Cowlitz River	287	36600	128
Hood River	329	34000	103
McKenzie River	345	16500	48
M. F. Willamette River	392	34000	87
Clackamas River	479	34800	73
Lewis River	481	54400	113
Clackamas River	657	60800	93
N. Santiam River	665	76600	115
Lewis River	731	129000	177
M. Fk. Willamette River	924	82200	89
McKenzie River	930	64400	69
Cowlitz River	1042	33800	32

Coast Range

Stream	Area at Gaging Station	Peak Flow	CSM
Grave Creek	22	3550	161
Slate Creek	30.9	4020	130
Youngs River	40.1	6300	157
Emigrant Creek	64	5260	82
Coast Fk. Willamette River	69	8800	128
Sucker Creek	76	6580	88
Trask River	143	30000	188
Wilson River	159	30000	188
S. Fk. Coquille River	169	30500	181
Siletz River	202	40800	202
Rogue River	332	11900	36
Alsea River	334	27800	83
Illinois River	346	52000	150
Nehalem River	667	36900	55

*Maximum of record for streams studied.
**Maximum of record period (47 years) for Bull Run River at site of Bull Run Dam No. 2.

abutments contain no solid rock except at extreme depth, a rock and earth type dam has been selected as the most feasible for this site. Plate No. 7 of the Appendix indicates the proposed cross-section of Bull Run Dam No. 2. The report of the Shannon and Wilson, Soils Engineers on the earth portion of the dam is in the Appendix.

The impervious portion of the dam is the core which will start with a width of 40 feet some 15 feet below the river bed and extend up the entire dam with a width of approximately 12 feet at the top. This core will be made of compacted clay and weathered Rhododendron material and will be sloping as indicated on Plate 7. On each face of the core will be filter material of graded sand and gravel (2" and less in size) to prevent any loss of the clay should the pool level be reduced materially over a short period of time. A filter of the same material on the downstream side will prevent any clay particles from passing through the filter to the select zone of pervious material which may be induced by the water level behind the dam saturating the core, resulting in a relatively small amount of water passing to the filter. The select zone is a zone of very pervious materials so that any water that does pass through the core will be passed through this zone to the select zone on the river bed and out below the dam at the toe. The shell material will be from the excavation of the spillway which appears to be primarily the Rhododendron material identified on the geological sections shown on Plate 3, Appendix. Both faces of the dam will be riprapped to a minimum of three feet.

There exists a weak clay lens beneath the toe of the dam at about elevation 723. It is proposed to excavate down and remove this clay layer and backfill with a five foot thick filter layer before adding the select zone and shell portion of the dam.

The relatively mild slope of the face of the dam serves to spread the mass over a large area and thus decrease the soil pressures and resultant settlement. It also provides an adequate factor of safety against sliding or slipping of the material within and below the dam. The axis of the dam is curved having a radius of 2000 feet so that hydrostatic forces will set up horizontal compressive forces within the core material.

Prior to and during construction of the dam, coffer-dams will be built upstream and downstream to permit dry work in the river channel. It is planned to incorporate the upstream coffer-dam as part of the upstream shell while the downstream coffer-dam will have to be removed upon completion of the project. In order to insure no water passing underneath the core material, extensive grouting operations will be carried on. This grout will be carried to the basalt rock as indicated on the section through the dam, Plate 7, Appendix. The grouting operation will be carried up each abutment along the axis of the core. This grouting will tie in with the grout around the diversion tunnel so that we have a complete barrier for the passing of water extending under the dam and through the abutments at the construction zones.

The dam will be constructed by placing compacted layers of clay and weathered Rhododendron material in the core in layers 6 inches thick over a foundation that has been stripped of humus and surface gravels and following the grouting operations. A shell material will be placed in layers of approximately 12 inches and compacted thoroughly. In the removal of the weak clay lens below the axis of the dam it will be necessary to excavate relatively narrow strips at right angles to the river and backfill all these strips before a second strip is excavated. This procedure will be followed in order to prevent any sloughing of the abutments which could occur if all of this material were to be removed at one time and the backfill attempted at a later period. By replacing the material in relatively narrow strips at right angles to the channel the strength of the toe of each abutment will be returned to the original conditions as nearly as possible. The riprap will be placed by dump methods rather than hand placed. The actual thickness of this riprap will be a minimum of three feet and will vary between three and five feet depending upon the equipment used in dumping the riprap.. This riprap will be of basalt rock quarried from nearby sites.

Spillway

Spillways of adequate capacity and correct design are essential to the safety of dams and structures downstream whenever more water flows into a reservoir than can be permanently stored therein. An earth dam is subjected to such severe loss of material and strength that it may be washed out if overtopped. Overtopping must be absolutely prevented by a spillway at the proposed dam. Far more important than the financial loss of the dam and its contents, a washout would carry earth and rock into the Headworks of the conduits bringing water into Portland and could destroy the Headworks structures.

In order to carry away the excess flood water of the Bull Run River a spillway capacity of 30,000 cfs has been selected. This capacity was determined after a study had been made of floods in western Oregon and Washington and is 50% greater than the recorded flood of Bull Run River. Although the capacity of the outlet works and powerhouse were not considered in selecting a spillway capacity, the additional release of water through these facilities represents an increased factor of safety against overtopping.

The length and hydraulic characteristics of a spillway govern the head needed to discharge a certain flow rate over that structure. A 45 degree sawtooth, free overfall, ungated spillway 600 feet long has been chosen as appropriate to the proposed damsite because such a long structure of this form combines the features of low head with minimum space requirement. While a low head is not in itself a necessarily desirable hydraulic characteristic, in this case it has the advantage of permitting the top elevation of the dam to be low, thus minimizing the material requirements of the dam. A total head of six feet is needed to discharge 30,000 cfs over the spillway proposed.

A spillway of this size cannot be made integral with an earth dam because seepage and differential settlement between the spillway structure and the dam would hazard the safety of both. For this reason, spillway sites removed from the dam have been studied. Owing to the desirability of locating the diversion tunnel, major outlet works, and powerhouse on the northern side of the river, spillway sites on the opposite side have been selected.

The topography of the south abutment area suggests two locations for spillways. One of these is about 200 feet south of the south abutment of the dam. For this site a spillway discharging into a lateral channel connected to a steep chute that leads to the river upstream of the Headworks is proposed. This is referred to herein as the "Chute Spillway", see Plate 9 of the Appendix. The other location is about 300 feet farther south. At this point a spillway discharging into a long canal leading to the river about 2000 feet downstream from the Headworks is proposed, referred to herein as the "Canal Spillway", see Plate 8 of the Appendix.

Several problems are created by the spillway discharging into the river upstream from the Headworks. Perhaps most serious of these are the dissipation of the energy of the water leaving the chute and control of erosion of the north river bank. As the water leaves the chute, it has a velocity of 80 fps (feet per second) and would bore a hole in the opposite bank unless deflected. There is insufficient depth to create a hydraulic jump and at such high velocities dental dissipators in the chute have little effect, so a tossing bucket is used to throw the spillway discharge into the air so that it will fall as a spray with reduced energy. Even if protected by riprap, the banks opposite the chute may be eroded by the spray, and muddy water will drain into the river, some of which will flow into the conduits leading into the City. A more effective bank protection plan would be costly. A nearly parallel entrance to the river requires an excessively long chute or a curve at the discharge end, and the high velocities involve make such a curve impractical. Before the "Chute Spillway" is adopted hydraulic model tests will be needed to determine the proper action for the water passing out of the lower section of the spillway.

The Headworks diversion dam has a capacity of about 28,000 cfs. Raising the dam wing walls would be necessary to protect the Headworks against a 30,000 cfs discharge.

None of the above features apply to the "Canal Spillway" and long canal arrangement which has the further advantage of providing from its excavation about all the material needed in the shell and core of the dam. Since about 1800 feet of the canal is unlined, the velocities in the canal must be low to prevent erosion, expecially retrogressive erosion to and under the concrete section. By making the bottom slope small and keeping the width to a minimum of 200 feet, a maximum velocity of 10 fps is attained in the earth section at a discharge of 30,000 cfs.

At the end of the earth portion, the canal slope is increased as it enters a block of hard Rhododendron formation, and finally the canal terminates in a cataract falling into a stilling pool excavated in basalt. From the stilling pool the discharge flows over Conduit No. 3, which would be re-laid and covered with concrete in a deep trench cut through basalt, and thence into Bull Run River. This arrangement will sever the south side service road. Access can be had from both ends although it does leave only one road access to the Headworks.

Either of the two spillways described above could safely discharge 30,000 cfs. A combination of the two with the chute spillway designed for 20,000 cfs and the canal serving as an emergency outlet was considered. This arrangement would not solve any of the problems involved with a flood discharging into the river above the Headworks save the extension of the Headworks protection.

Additional exploratory work is being undertaken to determine the feasibility of constructing the canal spillway. The advantages of this spillway make it the first choice as to spillway type and location. However, to pass all winter floods every year through this earth canal with the possibilities of erosion that could take place requires careful consideration of what can happen to the structures over an extremely long period of time. Until the results of the additional exploratory drilling has been available, no final decision can be made.

Diversion Tunnel

During the construction period it is necessary to have a diversion tunnel to by-pass the water around the construction zone. The diversion tunnel will supply the water to the City of Portland as well as pass a reasonable amount of flood water. The volume of flood water that must be passed depends upon the period of the year during which construction is underway. Since this is an earth dam, it is anticipated that the construction will start sometime in April or May, and, if possible, completion of the earth portion of the dam will be made during the one summer season. It is assumed that the Contractor will build the upper coffer-dam to elevation 775. Assuming the water surface at elevation 775 at the entrance to the diversion tunnel and assuming that the period during which the diversion tunnel is needed for construction purposes as starting with May 1, there have been only three times during which a flood in excess of 3500 cfs has occurred during the months immediately following May 1. These dates have been during June 1933, when the flood intensity was 9740 cfs for a very short time, June 1937 the flood flow was 4000 cfs and May 1945 when the flood flow was 4360 cfs. This covers the period of 1929 through 1953.

It is possible to maintain a water surface level in Lake Ben Morrow that is some 15 or 20 feet below the spillway crest of 1036. This would provide storage for some flood waters before their passing on downstream to the site of the construction. Therefore, it is our judgement that a diversion tunnel having a capacity of 3500 cfs would be adequate for the period following May 1, and that the diversion tunnel size should be equivalent to a 15 foot diameter pipe. This tunnel will be approximately 1000 feet long and will discharge downstream from the lower coffer dam. Any flood during October or November will be adequately handled because the height of the dam will be such as will create considerably more head on the entrance to the diversion tunnel than would come from the cofferdam along,and thus we can pass considerably more water at those periods. If it is found desirable to carry the construction over to a second season, it would be necessary to riprap heavily the top of the dam at the elevation where the operations would cease in the fall in order to protect the dam should over-topping occur. Given a normal construction season it is believed that the placement of the earth dam can be completed during one season. However, there is a possibility that, due to the clay lenses at or near the upstream toe of the dam, it might be desirable to place the fill or dam in such a way that the clay will consolidate as the work progresses. This means a slower operation and would very likely result in a two season construction project. If this is necessary the dam would be carried up to about one third its height the first season and completed the following season. A decision in this matter will be made following the determination of the strength of these clay lenses which will require additional underground explorations.

Water Supply Intake

The diversion tunnel must be constructed ahead of any operations for the dam itself for two reasons; first, it is necessary to have a continuous supply of domestic water to the City of Portland and, second, in order that flood waters can be passed by the construction zone. In order to supply water to the City of Portland it will be necessary to have the intake works completed as a part of the diversion tunnel construction. The proposed intake is shown on Plate 10 of the Appendix. The invert of the intake gates has been placed at elevation 758. Two 8' x 12' high gates are to be provided to completely shut the water off to the diversion tunnel. In addition two 48-inch diameter pipes will receive water from behind the trash racks and to each side of the 8' x 12' gates. Two 6' x 6' sluice gates will control the water to these two intakes. The two four-foot diameter pipes which will be part of the diversion tunnel construction are to supply water to the City of

Portland at times the 15 foot diameter diversion tunnel is closed for connection to the power plant.

The outlet structures of the diversion tunnel and the two 48-inch water supply pipes are shown on Plate 11, of the Appendix. It is proposed to place one Howell-Bunger valve at the end of each 48-inch pipe. The structure will provide for a steel lined concrete hood in order to control the spray from the Howell-Bunger valves. These Howell-Bunger valves will be motor operated. The diversion tunnel Contractor will be required to construct all of the facilities shown on Plate 11 except the transition from the 15' diameter tunnel to the 8' diameter and the butterfly valve. The Contractor for the dam proper will be required to add the transition section and the 96-inch butterfly valve. This can be done after the gates have been closed and water is being stored behind the dam. During this period water can be supplied to the City of Portland through the two 48-inch pipes and the Howell-Bunger valves. The 8' diameter butterfly valve is included in order that we will have a means to drain the reservoir for inspection should that ever become necessary.

Service to the intake tower will be by boat or barge. A bridge could be constructed to the intake tower, but it has been omitted from our estimate because of the excessive cost and the fact that a bridge to such a tower is seldomly used.. Due to the possibility of slides during construction or later the intake tower has been placed at the river bank with a minimum amount of excavation in the north abutment. Consequently any bridge construction would require extremely high piers which would increase the cost of bridgework. It is believed that a bridge for one-way traffic to be used by trucks servicing the intake tower would cost approximately $200,000. Any equipment necessary could be barged to the intake tower and, by means of a crane or hoist mounted on top of the tower, be lifted and put in place as may be required. A boat could be used for occasional trips of personnel to the intake tower. Safety type ladders will be provided for access to the operating floor.

PART II

HYDROELECTRIC POWER

General

Bull Run Dam No. 1 was constructed with two eight foot diameter penstocks for the future installation of hydroelectric facilities when and if such became feasible. The available head is nominally 172'. During the winter time water passes over the spillway without being placed to beneficial use. This period of spilling water is generally from October 15th through June 15th.

The critical months for hydroelectric power in the Pacific Northwest are September through April. During the remainder of the year, due to the flood water of the Columbia River and its tributaries, there is ample hydroelectric power through the Pacific Northwest. Any power generated after about April 15th will be of relatively little value since the market is more or less flooded with secondary hydroelectric energy. However, energy generated between October 15th and the middle of April is of considerable value to the power hungry northwest.

The value of power is of course dependent upon its availability and the cost of developing and producing the power. It is understood that the private power companies have negotiated contracts with the Grant County PUD for power to be generated at their two Columbia River plants for approximately three mills per kilowatt hour. This would appear to be the minimum value of any power that would be generated if generating facilities are placed at the dams of City of Portland. The present maximum value of the power would be related to the cost of power imported during the past winter months. Approximately 60,000 kw capacity was imported from COPCO (California and Oregon Power Co.) during the past winter at approximately 6 1/2 mills. The power was a blend of steam and hydro. Therefore, it would appear that hydroelectric power generated by the City of Portland would have a minimum value of 3 mills and a maximum value of 6 1/2 mills. If the maximum value were placed upon energy, it could, of course, only be used during those winter months when power could not be obtained elsewhere. In fact such a high cost energy might not be used in more than one year out of three to five. Therefore, in order to sell the energy as it is avilable each year, the selling price must be down in the lower portion of the 3 to 6 1/2 mill range.

The construction of power facilities at the two dams of the City of Portland must take into account the income which can be received for the power generated. Therefore, the financing, construction, and operation of power generating facilities must be considered within a 4 or 4 1/2 mill maximum value per kilowatt hour of power produced. If the overall cost exceeded this figure, it would not be economically feasible to construct these power facilities until the entire Pacific Northwest were on a thermal power basis rather than a hydro basis. Present thermal power costs are between 8 and 10 mills and naturally these facilities are not used except during emergencies. This also indicates that, if the power facilities can be constructed within the 4 or 4 1/2 mill requirement, when the Pacific Northwest does go on a thermal basis the power generated by the facilities proposed would be worth at least the value of the fuel for a thermal plant. Should the Pacific Northwest be on a thermal basis in some 15 years as some engineers believe, the value of the kilowatt hours produced at the plants proposed would be probably 50 per cent more than at the present time.

Bull Run Dam No. 1

Scope

The powerhouse proposed for the existing Bull Run Dam No. 1 would contain two generating units and associated auxiliary equipment, see Plates 12, 13, 14 and 15 of the Appendix. The building would be located adjacent to the dam and the north spillway wall. The entire structure below elevation 879.0 would be of reinforced concrete while the main superstructure would be of structural steel with insulated metal siding. A new access road having a maximum grade of 10% would be constructed to the powerhouse.

Water Available

Normally the only period during which water in satisfactory quantities is available will be the time from October 15th thru June 15th. From June 15th thru October 15th the only water that can be used for power generation purposes is that which is released for domestic consumption to the City.

The median water available at Lake Ben Morrow for the 25 year period following the construction of Bull Run Dam No. 2 is shown in the following table:

TABLE II

Hydro Flow - Bull Run No. 1

Flows corrected for Storage in Lake Ben Morrow

Month	Median Flow c.f.s.	1936-7 Flows c.f.s.
Oct.	283	63
Nov.	821	36
Dec.	932	932
Jan.	750	160
Feb.	781	498
Mar.	704	868
April	757	1257
May	697	1043
June	394	803
July	168	168
Aug.	84	98
Sept.	84	93

Potential Power

The critical hydroelectric period in the Pacific Northwest is considered as the September thru March, 1936-7 period. The flows for the water year October thru September, 1936-7 are also given in the above Table II.

The median flows are those of the period of record where there are as many mean monthly flows above as below these figures. The capacity of the generating units can be based upon the median flows. The result will be units of a size that had they been installed for the period of record they would have operated at full capacity or at an overload just as many months as they would have operated below capacity.

The physical conditions of the intake and penstocks have a limiting affect upon the size of units to be installed. The two existing penstocks are 8'-0" in diameter and have a 7'-6" butterfly valve in the line. The head loss thru these units is such as to indicate that units of 8000 to 9000 kw are about the maximum size that should be installed.

The use of the water for power will depend upon the power needs and the times the water is available. Normally the greatest need for power is between 7 AM and 11 PM, Mondays thru Fridays. It is desirable to have storage to so operate the generating equipment. This storage is available at Bull Run Dam No. 1. The time factor involved requires a water release of a little over twice that available as inflow with the reservoir full during the 16 hour, 5 day operational program. Using such a time factor and median water, the potential monthly generating capacity would be as indicated in Table III below:

TABLE III

POWER POTENTIAL AT BULL RUN DAM NO. 1

(Median Water)

Month	Median Flow c.f.s.	Time Factor	Adjusted Flow c.f.s.	KW Potential *
Oct.	283	2.21	625	7719
Nov.	821	2.14	1760	21736
Dec.	932	2.11	1970	24330
Jan.	750	2.11	1580	19513
Feb.	781	2.10	1640	20254
Mar.	704	2.21	1550	19143
Apr.	757	2.14	1620	20007
May	697	2.11	1470	18154
June	394	2.25	886	10942
July	168	2.11	354	4371
Aug.	84	2.11	178	2198
Sept.	84	2.14	180	2223

*Potential KW capacity if generating units are operated 16 hrs/day 5 day/week. Assumed 88% eff. for turbines and 96% for generators.

The actual size of the units to be selected must be a compromise since no two years are alike as far as stream flow is concerned. Based upon two 8000 kva generators having 15% overload capacity, the number of hours per day the units can operate with the water available and the energy generated are shown on Table IV.

TABLE IV

POWER PRODUCED BY 2 - 8000 KVA UNITS

BULL RUN DAM NO. 1

Month	Median Flow c. f. s.	Hrs/day 5 da. week	KW Hr.
Oct.	283	12.3*	2,600,000
Nov.	821	18.8	7,290,000
Dec.	932	21.2	8,560,000
Jan.	750	17.0	6,900,000
Feb.	781	17.7	6,500,000
Mar.	704	16.8	6,460,000
Apr.	757	17.2	6,640,000
May	697	15.8	6,400,000
June	394	19.0*	3,500,000
July	168	7.6*	1,550,000
Aug.	84	3.8*	775,000
Sept.	84	3.7*	710,000
		Total	57,885,000

*One 8000 kva generator in operation.

The power potential during the months of July, August, September, and portions of June and October will be approximately that shown. The actual generation will be dependent upon the water released from storage for domestic use and the residual head behind the dam. Basically the annual power output from median water will be as indicated in Table IV. Further, the potential is figured on median monthly flows, and the operation when the units are installed will be with the actual water available each day.

Pertinent Data

The pertinent data for the installation at Bull Run Dam No. 1 are as follows:

Location

Between spillway and north bank approximately 30 feet from the face of the dam.

Stream Flow

Total Drainage Area, square miles	74
Flow Characteristics, annual median, cfs	538

Headwater Elevation, Feet (M. S. L.)

Normal Pool	1036
Maximum Pool (with 8' gates)	1044
Maximum Spillway Design Flood, cfs	21000

Tailwater Elevations, Feet (M. S. L.)

Minimum	860
Maximum	877
Normal	864

Power Data

Gross Storage, Acre Feet	31000
Net Head, ft.	
Rated (For Turbine Design)	172
Maximum	178
Minimum	167
Plant Output	
Normal Full Load Rating, KVA	16000
Guaranteed Continuous Rating, KVA	18400
Total Average Annual Energy, MWH	57885

Powerhouse Structure

Size, feet	89x58
Type	Enclosed
Elevations:	
Generator Floor, Elev.	879
Turbine Floor, Elev.	865

Penstocks

Number	2
Inside Diameter, ft.	8'-0"
Length, ft.	165

Generators

Number	2
Speed - RPM	240
Rating, KVA	8000
Voltage	4160
Cooling	Forced air
Exciters	Direct connected
Neutral Grounding	Transformer

Turbines

Number	2
Speed - RPM	240
Rating, HP	13000
Type	Francis
Rotation	Clockwise

Main Power Transformer

Number	1
Capacity, KVA	20000
Voltage Rating	57000/3950
Cooling, Forced (FOW)	Water

Station Service Power - AC

Transformer: KVA	112.5
Stand-by Gas Generator: KW	60

Station Service Power - DC

Battery	125 volts

4160 Volt Switchgear

Type, Indoor	Metalclad
Current Rating	2000
Interrupting Capacity, MW	150
Type of Breakers	Air

Powerhouse Crane

Capacity, Tons	40

Compressed Air Supply

Station Supply, Pressure	100 psi.
Governor Supply, Pressure	300 psi.

Water to Rosyln Lake

General

Before discussing the power potential at Bull Run Dam No. 2, the effects of supplying excess water to Rosyln Lake, the forebay to the hydro-electric powerhouse on Bull Run River owned and operated by PGE (Portland General Electric Co.) should be considered. Conduits Nos. 2 and 4 pass by Rosyln Lake, and by a relatively small expenditure, excess water from winter flows of the Bull Run River could be supplied to Rosyln Lake. Thus the City could sell falling water to PGE for use thru a new turbine which they would install.

At the present Conduit No. 3 can supply the winter demand of the City for domestic use. However, all conduits are needed during the summer. In fact, the summer peak day during 1956 was 180 mgd and the capability of the three conduits (Nos. 2, 3 and 4) is 225 mgd. The City's requirements are going up each year and a fourth conduit should be constructed within 10 years and at most 15 years. Therefore, since a new conduit will be needed in such a short time, the potential of this conduit to supply winter flow to Rosyln Lake should be considered.

Therefore, the criteria for the water available to be sold to PGE are as follows:

1. That water which is not needed for domestic purposes by City of Portland,

2. That water which can be conveyed to Rosyln Lake by Conduit No. 2,

3. That water which can be conveyed to Rosyln Lake by Conduit No. 5, the new conduit.

4. Conduit No. 4 will not be available since it is contemplated to connect Conduit No. 4 behind Bull Run Dam No. 2 for delivery to a higher level than is now delivered by gravity to the west hills of Portland, and

5. The water to be conveyed by Conduit No. 4 during the winter will not be available for power at Bull Run Dam No. 2 nor at Rosyln Lake.

Potential for the Sale of Water to PGE

The hydraulic analyses show that 120 cfs can be carried by Conduit No. 2 from the Headworks to Rosyln Lake. This would be drawn from excess winter flows from about October 15th thru June 15th of each year. If this water is not sold to PGE it will pass down Bull Run River without beneficial use to the City.

The size of a fourth conduit to the City should be at least as large as Conduit No. 4, which is a 66-inch line. Since space for a conduit is at a premium in the Bull Run Canyon, it is recommended that a 78-inch line be installed. Assuming that a 78-inch line is laid, its capacity to Rosyln Lake would be 360 cfs. Thus 480 cfs could be sold for the period it is available as excess winter flow. All of this water is now going down the stream without being put to beneficial use.

In terms of kwhr of electric energy, the water available to the City for sale to PGE would have a potential of 64,000,000 kwhr of energy per year based upon median water. The cost of the 78-inch line from the Headworks to Rosyln Lake is estimated to be $2,261,500. At 2.8% interest for 30 years the annual debt service on bonds in this sum would be $112,000. The sale price of the water would have to be equivalent to 1.75 mills per kwhr in order to retire the entire cost of the pipe line.

The cost of construction for a powerhouse having a single 16,500 kw generating unit as proposed by PGE would be about $1,750,000.00 or equivalent to 2.74 mills per kwhr, assuming a requirement of 10% per annum on the investment for all costs including financing, taxes, administration, and profit. The total would be equivalent to 4.49 mill power which is not out of line for power developments of this nature. The Pelton Project, according to PGE, will produce 400,000,000 kwhr annually. The present official estimated cost is $20,500,000. This would be 5,125 mill power if a 10% annual charge is made. Permission for a fast write-off makes this project more attractive during the earlier years of its life.

The income to be obtained from the sale of water to PGE should pay some portion of the cost of the 78-inch conduit. The conduit will become a part of the transmission system to the City of Portland, and its cost is a proper charge for transmission of water to the City. Therefore, the rate structure for the sale of water to PGE must be subject to negotiation between the City and the Company. Power calculations are based upon median water for the period since 1929. Upon that basis it is our judgment that the water could be supplied for a period of 50 years or more. This time element is of importance in the negotiation.

Bull Run Dam No. 2

Scope

The powerhouse proposed at Bull Run Dam No. 2 would contain one generating unit and associated auxiliary equipment. The building would be located against the north bank of the river between the diversion tunnel discharge and the toe of the dam. The entire structure below elevation 765.0 would be of reinforced concrete while the main super-structure would be of structural steel with insulated metal siding. The building would be similar in appearance to the powerhouse proposed for Bull Run Dam No. 1 except smaller in size.

Water Available

As for the powerhouse at Bull Run Dam No. 1, the only period during which water in satisfactory quantities is available will be the time from about October 15th thru June 15th. From June 15th thru October 15th the only water that can be used for power generation purposes is that which is released for domestic consumption to the City.

The median water available at Bull Run Dam No. 2 as indicated by the records since 1929 is shown on Table V. The monthly mean flows for the water year 1936-7 are also given.

TABLE V

HYDRO FLOWS AT BULL RUN DAM NO. 2
(Flows corrected for Releases from Lake Ben Morrow)

Month	Median Flows c. f. s.	1936-7 Flows c. f. s.
Oct.	381	82
Nov.	966	64
Dec.	1197	1197
Jan.	981	240
Feb.	1017	665
Mar.	861	1151
Apr.	952	1651
May	827	1287
June	469	1010
July	200	209
Aug.	105	119
Sept.	109	114

The flows during the water year October to September, 1936-7 are given to indicate the flows which occurred during the assumed critical water year of 1936-7 for the entire Pacific Northwest. However, the power studies are based upon median water.

Potential Power

The installed capacity of the generating unit to develop the potential power at Bull Run Dam No. 2 is affected by the methods of using the available water. Since it is proposed to connect Conduit No. 4 to an intake behind the dam to use the additional 110 ft. of head to convey water to the west hills of Portland to avoid some pumping within the City, the water so conveyed will not be available for use thru the turbines. The water delivered to the City other than thru Conduit No 4 will be upon a 24-hour, 7 days per week basis as will be the water conveyed to Rosyln Lake for PGE. Therefore, these waters must be used to generate power 24-hours per day. The excess water can be used to generate power between 7 AM and 11 PM as it is available.

The smallest size unit will result when the generator is operated at capacity 24 hours per day 7 days per week. The methods of using the water as outlined above results in a compromise. Based upon such a compromise a single 8000 kva unit is proposed. The power from such a unit based upon median water is shown in Table VI.

TABLE VI

POWER PRODUCED BY ONE 8000 KVA UNIT

BULL RUN DAM NO. 2

Month	Median Flow (cfs)	Less 60 cfs to Conduit No. 4	24 Hr. Flow (cfs) to City & Rosyln Lake	Excess Flow cfs	Total KW Hrs.
Oct.	381	321	321	-	1,735,000
Nov.	966	906	580	326	4,855,000
Dec.	1197	1137	580	557	6,319,000
Jan.	981	921	580	341	5,130,000
Feb.	1017	957	580	377	4,830,000
Mar.	861	801	580	221	4,480,000
Apr.	952	892	580	312	4,855,000
May	827	767	580	187	4,340,000
June	469	409	409	-	2,200,000
July	200	140	140	-	780,000
Aug.	105	45	45	-	253,000
Sept.	109	49	49	-	265,000
			Total KW hrs.		40,042,000

NOTE: 60 cfs is assumed to by-pass power plant directly to Conduit No. 4 and it is assumed that 480 cfs is sold to PGE 24 hours per day 7 days per week when it is available.

The power generated during the summer months will be increased somewhat due to water released from storage. Basically the power produced by the single 8000 kva unit will be 40,042 mwhrsper year based upon median water.

Pertinent Data

The pertinent data for the installation at Bull Run Dam No. 2 are as follows:

Location

On the north bank, just downstream from the toe of the dam.

Stream Flow

Total Drainage Area, Square Miles	102
Flow Characteristics, annual median, cfs	672

Headwater Elevation, Feet (M. S. L.)

Normal Pool	860
Maximum Pool	866
Maximum Spillway Design Flood, cfs	30,000

Tailwater Elevations, Feet (M. S. L.)

Minimum	748
Maximum	762
Normal	749

Power Data

Gross Storage, Acre Feet	21,000
Net head, ft.	
Rated (For Turbine Design)	111
Maximum	118
Minimum	98
Plant Output	
Normal Full Load Rating, KVA	8,000
Guaranteed Condinuous Rating, KVA	9,200
Total Average Annual Energy, MWH	40,042

Powerhouse Structure

Size, feet	67x60
Type	Enclosed
Elevations:	
Generator Floor	765
Turbine Floor	751

Penstocks

Number	1
Inside Diameter, ft.	11.0
Length, ft.	50

Generators

Number	1
Speed - RPM	188
Rating, KVA	8,000
Voltage	4,160
Cooling	Forced Air
Exciters	Directly connected
Neutral Grounding	Transformer

Turbines

Number	1
Speed - RPM	188
Rating, HP	13,000
Type	Francis
Rotation	Clockwise

Main Power Transformer

Number	1
Capacity, KVA	10,000
Voltage Rating, KV	57000/3950
Cooling, Forced	Air

Station Service Power - AC

Transformer, KVA	112.5
Stand-by Gas Generator, KW	60

Station Service Power - DC

Battery	125 volts

4160 Volt Switchgear

Type, Indoor	Metalclad
Current Rating	2,000
Interrupting Capacity, MVA	150
Type of Breakers	Air

Powerhouse Crane

Capacity, Tons	40

Compressed Air Supply

Station Supply, Pressure	100 psi
Governor Supply, Pressure	300 psi

Summary of Power Potential

The estimate of the annual power that can be produced based upon median water by the hydroelectric power plants proposed for Bull Run Dams Nos. 1 and 2 are:

Bull Run Dam No. 1	57,885,000 kwhrs
Bull Run Dam No. 2	40,042,000 kwhrs
Total	97,927,000 kwhrs

or 98,000,000 kwhrs (rounded)

The estimated cost of the two power plants and the transmission system is $3,798,700 . Based upon an assumed required 10% annual return the power would cost 3.87 mills based upon median water.

The 98,000,000 kwhrs of energy cannot be considered as firm power but is that energy which is available as an average over a FPC license period (50 years). The firm power would be that which is available during the 1936-7 critical period considered for the Northwest Power Pool.

Basically, Bull Run River is not a good power stream in itself but only in connection with a much larger source of power, either hydro or steam. The power facilities recommended, therefore, are based upon their addition to an existing power system.

It might be well to point out that the above conclusion was made in a report to the City during the early nineteen thirties. In the same report the recommended plan for development at Bull Run Dam No. 1 (Bear Creek Dam) was identified as "Plan 3" in that report with the following installed capacity:

No. of Units		Horse Power of Turbines	KW of Generators
1		9400	6744
2		4700	3372
	Total	18800	13488

The average annual energy potential at 100% load factor was estimated to be 54,503,664 kwhrs. The units recommended in this report are two 8000 kva or a total of 16000 kva installed capacity. The slightly larger sizes will be of value in their operation within a larger power system in using somewhat higher flows with less spilling of water from the reservoir.

PART III

CONSTRUCTION COST ESTIMATES

General

The first interest of the City is the cost of a dam and appurtenant facilities necessary to store and pass the water needed for domestic purposes. Therefore, the minimum needs at the site proposed are (1) dam, (2) spillway, and (3) diversion tunnel and intake tower. For reason of safety to the water supply of the City a high level intake thru the south abutment is proposed taking water from elevation 820.0, some 40 feet below normal reservoir surface. About 60% of the reservoir capacity would be available to this level intake. The high level intake is connected directly to Conduit No. 4 to provide an additional 110 feet of head for delivery to Portland's west side. An alternate high level intake is proposed for the delivery of water to the forebay of the Headworks dam.

The estimates of costs for power installation at Bull Run Dam No. 2 are based upon the assumption that water will be delivered to Rosyln Lake thru a new supply conduit of 78-inch diameter, otherwise a single larger unit or two smaller units could be installed having a total capacity of about 12000 kw.

Costs for Dam, Spillway and Diversion Structures

The construction cost estimates for the dam are as follows:

Construction Cost for Dam

Stripping for dam	7,900 c.y. @ $3.00	$ 23,700
Excavation	133,900 c.y. @ $1.25	167,400
Shell material	306,000 c.y. @ 0.40	122,400
Filter material	65,600 c.y. @ 2.50	164,000
Select material	139,000 c.y. @ 0.80	111,200
Core material	41,400 c.y. @ 2.00	82,800
Riprap	28,600 c.y. @ 3.00	85,800
Upper coffer-dam		28,500
Lower coffer-dam		30,000
Blanketing	30,000 c.y. @ 1.00	30,000
Dike		900
Roadway surface on dam proper		8,000
Grouting		50,000
Additional explorations		25,000
Clearing reservoir area	480 acres @ $200.00	96,000
	Sub-total	$1,025,700

Construction Cost for Canal Spillway

Excavation	581,000 c.y. @ $1.10	$ 639,100
Concrete	6,500 c.y. @ 50.00	325,000
Reinforcing Steel	850,000 lbs. @ 0.15	127,500
Relaying Conduit No. 3		30,000
	Sub-total	$1,121,600

Construction Cost for Diversion Tunnel and Intake Structures

Intake Tower

Excavation above El. 775 level	6,500 c.y. @ $1.80	$ 11,700
Excavation to El. 750 level	2,600 c.y. @ 2.05	5,330
Excavation for foundation	1,300 c.y. @ 2.30	2,990
Coffer-dam	6,500 c.y. @ 2.50	16,250
Foundation concrete	452 c.y. @ 42.00	18,980
Tower structure to El. 774	575 c.y. @ 60.00	34,500

Tower structure above El. 774	838 c.y. @	$80.00	$ 67,040
Reinforcing steel	204,000 lbs. @	0.15	30,600
Guides and miscellaneous items			20,700
Backfill around structure	2,600 c.y. @	2.15	5,590
Riprap	170 c.y. @	6.00	1,020
Gates, Trash racks and machinery			96,500
		Sub-total	$311,200

Diversion Tunnel (With 2-48" pipes)

Tunneling	10,800 c.y. @	$42.00	$453,600
Open excavation	4,160 c.y. @	1.95	8,100
Sheeting			6,300
Backfill in place	3,500 c.y. @	2.80	9,800
Hand and dump	1,640 c.y. @	0.45	740
Drainage	550 l.f. @	1.80	990
Concrete in tunnel	3,700 c.y. @	55.00	203,500
Concrete anchors	24 c.y. @	40.00	960
Steel tunnel lining	661,000 lbs. @	0.50	330,500
Stiffener rings	75,000 lbs. @	0.48	36,000
Concrete encasement under road	20 c.y. @	45.00	900
Water Pipes	193,500 lbs. @	0.33	63,860
Concrete encasement in open cut	170 c.y. @	45.00	7,650
		Sub-total	$1,122,900

Outlet Structures

Tunnel Outlet

Grading (lump)			$ 300
Concrete in place	155 c.y. @	$50.00	7,750
Reinforcing steel	19,500 lbs. @	0.15	2,930
Transition	9,200 lbs. @	0.40	3,680
Riprap	75 c.y. @	6.00	450
8' Diameter butterfly			38,000
Miscellaneous			990
		Sub-total	$ 54,100

Water Pipe Outlets

Valve house excavation	172 c.y. @ $ 1.90		$ 300
Concrete	132 c.y. @	55.00	7,260
Valve hoods	17,700 lbs. @	0.40	7,080
Riprap	80 c.y. @	6.00	480
2 - 48" Howell-Bunger Valves		Lump	57,000
Miscellaneous			1,350
	Sub-total		$ 73,500

Access Roads

Dam to Bear Creek Road		$ 4,000
Road to Outlet Structures		70,000
	Sub-total	$ 74,000

Summary for Dam and Appurtenant Facilities

Dam	$1,025,700
Canal spillway	1,121,600
Intake tower	311,200
Diversion tunnel	1,122,900
Tunnel outlet	54,100
Water pipe outlets	73,500
Access roads	74,000
Sub-total	$3,783,000
Plus 15% for Contingencies and engineering	567,000
Total	$4,350,000

High-Level Intake (South Abutment Connected to Conduit No. 4)

Intake	$ 22,700
Tunnel	271,400
Open cut	122,800
Outlet	41,000
Sub-total	$ 457,900
Plus 15% for Contingencies and engineering	68,700
Total	$ 526,600

Alternate High Level Intake (North Abutment)

Intake	$ 20,650
Tunnel	128,600
Outlet	53,500
Sub-total	$ 203,000
Plus 15% for Contingencies and engineering	30,500
Total	$ 233,500

Plate 11 shows two possible sections for the diversion tunnel. A detailed estimate was made for both. The one in the above estimate is for the two 48-inch water pipes placed on the outside of a 15'-0" diameter conduit. The estimate for the alternate 17'-6" diameter conduit is $1,093,500 without 15% for contingencies and engineering. The difference is $29,400 which sum is not within the limits of accuracy of such an estimate, therefore, for practical purposes both sections are considered to cost the same. The alternate section being circular is inherently stronger so in the final design this may be used or the contractor may be given his choice.

Costs for Powerhouses

The estimated construction costs for the powerhouses are as follows:

Bull Run Dam No. 1

Two generators	$ 410,000
Two turbines, governors, etc.	470,000
Transformer	110,000
Switchgear	90,000
Recording Equipment	9,000

Station service	$ 15,000
Crane	35,000
Miscellaneous electrical	42,000
Oil Equipment	15,000
Compressors, drainage pump, CO_2 system, Batteries, etc.	17,500
Standby gas engine generator	9,500
Miscellaneous equipment	28,500
Road	50,000
Powerhouse structure	438,500
Sub-total	$1,740,000
Plus 15% for contingencies and engineering	261,000
Total	$2,001,000

<u>Bull Run Dam No. 2</u>

Generator	$ 270,000
Turbine, governor, etc.	330,000
Transformers	65,000
Switchgear	55,000
Recording equipment	9,000
Station service	18,000
Crane	40,000
Miscellaneous electrical	35,000
Compressors, drainage pump, CO_2 system, batteries, etc.	20,000
Oil Equipment	12,000
Standby gas engine generator	9,500
Butterfly valve	50,000
Miscellaneous equipment	25,000
Powerhouse Structure	421,300
Sub-total	$1,359,800
Plus 15% for contingencies and engineering	204,000
Total	$1,563,800

Cost of Transmission Line

Clearing	10 mi. @	$2000	$ 20,000
Poles and hardware	423 units @	350.00	148,000
Labor	423 units @	60.00	25,400
Miscellaneous			10,000
	Sub-total		$203,400
Plus 15% for contingencies and engineering			30,500
	Total		$233,900

Summary of Costs for Power

Powerhouse at Bull Run Dam No. 1	$2,001,000
Powerhouse at Bull Run Dam No. 2	1,563,800
Transmission Lines	233,900
Total for power	$3,798,700

Pipe Line to Rosyln Lake

The line is proposed as a 78-inch diameter and would be approximately 25,000 feet long. No profile or field survey has been made so the estimate can only be considered approximate. The route would be generally the same as Conduit No. 4 although it may be laid on the opposite side of the river after final consideration. The approximate estimate is as follows:

78-Inch Transmission Line

Pipe in place	25,000 l.f.	@$55.00	$1,375,000
Excavation and backfill	25,000 l.f.	@ 10.00	250,000
Couplings	610	@150.00	91,500
Bridges			125,000
Construction at Roslyn Lake			125,000
Sub-total			$1,966,500
Plus 15% for contingencies and engineering			295,000
Total			$2,261,500

Cost per foot $90.50

Summary of Cost of Projects

The summary of costs for all projects are as follows:

Dam and appurtenant structures	$4,350,000	
High Level Intake	526,600	
Sub-total		$4,876,600
78-inch Conduit to Rosyln Lake	$2,261,500	
Sub-total		$7,138,100
Powerhouse at Bull Run Dam No. 1	$2,001,000	
Powerhouse at Bull Run Dam No. 2	1,563,800	
Transmission Line	233,900	
Grand total all projects		$10,936,800

PART IV

CONSTRUCTION PROCEDURE

General

Once a decision has been made to proceed with the work, it is important to establish a reasonable target date for placing the project in operation after due consideration for construction procedures. The minimum time would be one construction season for the diversion tunnel and a second construction season for the dam. The target date for completion would then be November, 1958 assuming a start not later than July 1, 1957. Should it be necessary, due to requirements for consolidation of the underlying clay layers, to use two summers for construction of the dam then the target date would be October, 1959.

Powerhouse construction is controlled primarily by delivery of equipment. Turbines will require some 500 days or more for delivery after the order is placed. Therefore, a completion date under 26 to 28 months is not realistic. If orders for generators and turbines could be placed by July 1957, then the units could be in operation by October 1959 at the start of the 1959-60 winter when hydro flows for power are available. It is, therefore, important in order to save one complete winter's production to place orders for these items by July 1957.

Tunnel and Intake Tower

As a first step for the construction of Bull Run Dam No. 2, a contract must be let for the diversion tunnel. This unit must be in operation prior to the start of work on the dam. The work which will have to be included are (1) intake tower, (2) diversion tunnel including steel liner, and (3) the outlet works.

The outlet works include the outlet control valves for the two 48-inch water supply lines, control building, and the concrete apron discharge unit for the 15-foot pipe. The 15'x8' transition and the 96-inch butterfly valve are not to be included with this work. These two items would be installed by the Contractor for the dam or powerhouse.

Coffer-dams

The coffer-dams will be the first operation of the Contractor for the dam in order to isolate this work and dewater the construction area. The Contractor will be required to pump any muddy water from the excavation over the Headworks dam in order not to contaminate the water supply to the City.

Although it is not shown on Plate 7, Appendix, the upper coffer-dam may have a five to seven foot layer of weathered Rhododendron material placed over the river bed. This layer of impervious material would be tied to the core of the dam, thus giving a longer path for any water that might tend to pass thru the dam.

Dam

At this time it is proposed to remove the clay lens under the downstream toe of the dam. This requires excavation to a depth of about

25 feet. Since the abutments are quite steep it is proposed to do this in steps, excavating a strip about 30 feet wide at right angles to the river. Backfilling will be accomplished with the necessary compaction prior to excavating a second strip. This is required in order to avoid removing a large mass of material on which the abutments may depend for stability.

The impervious core will contain clay and weathered Rhododendron material compacted in six inch layers. The filter material will be brought up simultaneously with the core as will the remainder of the dam. The filters will consist primarily of natural sand and gravel deposits upstream from the dam. The select material will be gravels from the river deposits with some of the coarse Rhododendron material from the spillway excavation. The shell material will come from the spillway excavation and will be compacted in 12-inch layers.

The upstream face of the dam will be riprapped. Although the downstream face is indicated on Plate 7 as being riprapped it may receive a gravel surface treatment only. If so, the gravel material will be primarily of 4-inch size and larger.

Spillway

Construction of the spillway will proceed simultaneously with the dam. The canal spillway is the one desired to be constructed but the final decision will be made after the additional exploratory work now underway is completed. Judgement as to the erosion downstream from the concrete section will be the deciding factor. It may be that a concrete control section and concrete lining at the end of the spillway may be decided upon in order to control retrogressive erosion from the bluff back up the spillway section.

Until actual discharges thru the spillway channel are obtained and observations made,we will not know what is going to take place. Therefore, it may be determined that the canal spillway will be constructed without the lower concrete control section, then, after three to five years of observations, determine the extent such control section is needed. In this way it may be possible to avoid altogether this expensive work. If finally required, it would be only a matter of postponing the expense for these observations as no serious damage would occur during such a short observation period.

Power Facilities

It is most important that bids be taken and an award for generating equipment be placed by July 1957 in order to have the two plants in operation by October 1959, the start of the winter hydro flows for power generation. A postponement of two or three months might be equivalent to a year's postponement as far as power is concerned.

If it is determined to go ahead with these power facilities, awards for generators and turbines could be made subject to financing. Financing can be by utility bonds to be paid out of revenues without a vote of the people or by general obligation bonds after a favorable vote. Water bonds as such cannot be used, since these are general obligation bonds and the City Charter specifically limits the use of funds from water bonds to water works improvements. The difference would be in the cost of financing, which is the higher cost of revenue as against general obligation bonds.

If equipment contracts are awarded in July 1957 construction contracts should be awarded by March 1, 1958 for completion by October 15, 1959. The contracts may be a part of or entirely separate from the dam. It would be desirable to receive bids on the dam and the powerhouses as separate bids at the same time and make awards to the lowest bidders whether or not one or three Contractors were involved. In the contract for the dam the requirement for the lower coffer-dam would be such as to permit the construction of the powerhouse within the area between the coffer-dams even though the powerhouse contract were by a different Contractor.

PART V

POWER POLICY

General Statement

Policy as to construction of power facilities must remain with the City Council and the people of Portland. Therefore, we do not propose to outline what that policy should be. It is discussed here only because of the necessity to present methods of approach to the problems involved for realizing the power potential of Bull Run River.

Bull Run River as a Power Stream

Alone, Bull Run River is not an economical power stream. Due to two conditions, it becomes economical to develop power available on Bull Run River namely

1. Storage has been and will be created for domestic water supply and capital expenditures for dams and appurtenant facilities are entirely chargeable to water supply, and

2. The existence of a large power supply system in the area of which the units on Bull Run River can become a part.

Methods for Accomplishing Construction

There are two methods whereby construction can be accomplished:

1. A power company could lease land from the City, construct the powerhouses and purchase falling water.

2. The City can construct the facilities at its expense and operate the facilities by anyone of the following methods:

a. Operation entirely by the City.

b. Employ a power company to operate the two powerhouses, or

c. Lease the facilities for operation by others.

If the first method is used the power company must finance the capital cost, pay taxes and all operating and maintenance costs. From the present bond market it would appear that money will cost either of the local power companies 5%. The amount of the taxes will depend upon the millage and assessed valuation. Clackamas County uses 25% of 80% of the market value for assessment determination, thus the assessed valuation would be about $760,000 for the facilities. Using a millage of 59.6 for eastern Clackamas County (1956-7 millage) the taxes would be estimated at $49,200. The approximate annual cost should the power company construct these faciltties would be

Debt service on $3,798,700 @ 5% (30 years)	$247,000
Operation and maintenance	50,000
Taxes	49,200
Cost of falling water 98,000,000 kwhr @ 0.75 mills (minimum)	73,500
Probable annual cost	$419,700

Including a $73,500 annual payment for falling water this sum is 11% of the capital cost. Basically, either of the local power companies must receive between 10 and 12% return on their capital investment. Therefore, if either power company would construct this facility the cost of power would be a minimum of $379,900 (10% of the capital cost) plus $73,500 or $443,400 compared to the approximate figure of $419, 700 above. The annual sum of $443, 400 would be equivalent to 4. 52 mills per kwhr based upon median water producing 98, 000, 000 kwhrs of energy.

Should the City construct the facility it appears that the total revenue to the City should approach the cost of power as if a private power company had financed and constructed the facilities. It is assumed that due to a more favorable interest rate, that general obligation bonds would be used to finance the work rather than utility bonds. The rate of interest on the last water bonds sold late in 1956 was 2. 8 per cent. The approximately annual cost would be

Debt service payment $3, 798, 700 @ 2. 8%(30 yrs)	$188, 000
Operation and maintenance	50, 000
	$238, 000

The approximate difference in annual cost would be $443, 400 less $238, 000 or $205, 400. Therefore, if the cost of the energy is 4. 52 mills should a private power company construct the work, the energy should be of the same value should the City construct and contract to sell the power. Under the latter the City would receive a net return of about $205, 400 compared to $73, 500 should falling water be sold for 0. 75 mill per kwhr equivalent.

There are various legal considerations that must be analyzed as well as the effect of possible changes in state laws as to taxes on municipal works of this nature. Should the City lease outright the facilities after they are constructed, we understand taxes become a liability, but in employing a party to operate no taxes would be paid and thus a sum in lieu of taxes could be returned to the City of Portland.

The energy available at 4.52 mills is less expensive energy than available from any known steam energy source and less than the cost of energy from the Pelton project. Based upon the greater net return to the City it is recommended that

1. The City immediately negotiate with Portland General Electric Co. or Pacific Power & Light Co. for the sale of the power and for operation of the two powerhouses.

2. The facilities for power be constructed by the City.

3. The City proceed on the assumption that, if necessary, utility bonds be used to finance the work but that a general obligation bond issue be submitted to the people for approval with revenue to be used to retire the bonds.

4. Specifications be prepared for the generators, turbines and transformers and a call of bids be issued for an award during July 1957.

Water to Rosyln Lake

Using the existing Conduit No. 2 and a new 78-inch conduit, 480 cfs can be delivered to Rosyln Lake to provide 64,000,000 kwhrs of energy. Here the City can only sell water. Therefore, the cost of the conduit can be financed by water bonds. At the interest rates for the latest bonds sold by the City, the debt service payment would be equivalent to 1.75 mills per kwhr of potential energy.

Whether or not the value of falling water at this location is equivalent to 1.75 mills per kwhr is relative. The additional cost for generating facilities must be considered. If these costs are equivalent to 2.74 mills as estimated, then the 4.49 mills total (2.74 + 1.75) are probably not excessive. Any value less than 1.75 mills equivalent for the water to Rosyln Lake would make the overall power from the three developments still more attractive.

In any negotiation toward a rate structure for this water, the City should keep in mind the alternate development of a plant by the City at Dodge Park about one and one-half miles toward the City from Rosyln Lake. At this point the head available would be near 400 feet rather than the 320 foot nominal head at Rosyln Lake available to PGE, producing about 80,000,000 kwhrs of energy compared to 64,000,000. Therefore, relative value of the water at the two places is of importance. All things being equal the existence of Rosyln Lake and the Bull Run Powerhouse of PGE with the needed penstock for a new power unit leads to the conclusion that the program to deliver water to Rosyln Lake should be followed if a satisfactory rate structure can be established for the water.

APPENDIX

REPORT TO

STEVENS AND THOMPSON

ENGINEERS, PORTLAND, OREGON

ON

PRELIMINARY DESIGN OF EARTH DAM

LOWER BULL RUN RESERVOIR

for the

CITY OF PORTLAND

OREGON

SHANNON AND WILSON

SOIL MECHANICS AND FOUNDATION ENGINEERS

SEATTLE, WASHINGTON

April 2, 1957

LIST OF FIGURES

PRELIMINARY DESIGN OF EARTH DAM

LOWER BULL RUN RESERVOIR

INTRODUCTION

The proposed site of the Lower Bull Run Dam and reservoir lies immediately upstream of the existing diversion dam and water supply intake, City of Portland, on the Bull Run River, Oregon.

This report presents the results of laboratory tests upon representative samples obtained from the foundation for the dam and from the proposed borrow, summarizes the stability analyses made to determine the preliminary design slopes of the earth dam, and presents preliminary recommendations for foundation treatment.

The geology of the site is presented in a separate report prepared by Lloyd Ruff, Consulting Geologist.

EXPLORATIONS

This site has been explored by twelve drill holes under contract by Lynch Brothers supervised by Stevens and Thompson, Engineers. From two of these borings, DH-11 and DH-12, we supervised the obtaining of seamless tube samples for laboratory testing. A large test pit was excavated with power equipment by the City of Portland near the control section for the proposed spillway. From this pit we obtained representative samples of the overburden and rock encountered.

The locations and logs of borings are contained on drawings prepared by Stevens and Thompson and are not appended hereto.

FOUNDATION CONDITIONS AT DAM SITE

The foundation soils in the valley bottom and on both abutments at the dam site as disclosed by the explorations to date consist of silty sand, gravel and boulders, in places well cemented and elsewhere compact or lightly cemented, containing lenses, pockets or strata of clay. The cemented portion is termed the Rhododendron Formation. The site is underlain at a depth of approximately 90' below river bed by basalt as encountered in DH-1.

On the abutments there are closed depressions in which water does not pond and at one location on the right abutment some distance from the site a small stream disappears into the ground in such a depression. Water was lost in some of the drill holes, particularly on the abutments. These are indications of very pervious strata in the foundation.

FOUNDATION CONDITIONS AT SPILLWAY

The spillway, based upon the test pit and upon visual observations, will be founded in its upper reaches upon a cemented silty sand and gravel, termed the Rhododendron formation. Overlying this to a variable and unknown depth are surficial deposits of clay and top soil, believed to be the result of weathering of the underlying Rhododendron formation.

LABORATORY TESTS

Since the clay pockets, lenses, or strata in the foundation are considered the weakest foundation material for the dam, two drill holes, DH-1l and DH-12, were put down specifically to obtain samples of these weaker materials. The use of powder in these holes was not permitted and two reasonably undisturbed samples of the clay and gravelly clay were recovered. From each of these samples it was possible to prepare only one specimen which was tested in the triaxial compression for shear strength. The results of these tests are contained in Fig. 1.

In addition to the shear strength, classification tests, consisting of natural water content and atterberg limits, summarized on Table I, were performed on the clay.

One sample was obtained of lightly cemented Rhododendron Formation from DH-11. The result of this test is also shown in Fig. 1.

Several Chunk samples of the residual clay overlying the Rhododendron formation were obtained from the test pit in the spillway area. The results of natural water content, unit weight and Atterberg Limits tests on seven selected samples are contained in Table II. Also shown in this table are the results of natural water content and unit weight tests on six chunk samples of the Rhododendron formation. The natural water content and unit dry weight data are plotted in Fig. 2.

Fig. 6 shows the results of a single shear strength determination on a specimen of laboratory compacted Rhododendron material.

EMBANKMENT SECTION AND FOUNDATION TREATMENT

The preliminary embankment section is shown in Fig. 7. In developing this section it is assumed that the clay in the foundation is not continuous but rather exists as lenses and pockets of limited extent. If it develops that there are one or more continuous clay layers having average shear strengths of less than 1.5 tons/sq. ft., they must either be removed or construction must be at a controlled rate such that excess pore pressure in the clay is not permitted. On Fig. 7 a section of foundation excavation is shown to provide removal of clay beneath the downstream portion. If it is necessary to slow down construction to prevent the development of excess pore pressure then the construction period may have to be increased to two seasons.

The foundation beneath the core both in the valley bottom and in the abutments should be grouted to provide an impervious cutoff. In the valley bottom the grout curtain should extent to the basalt; in the abutments the depth will depend upon the conditions but in general not less than 50' is recommended At the tunnel the grout curtain should be continuous between the dam and tunnel and should extend not less than 50' beneath and toward the abutment from the tunnel.

The purpose of the grout curtain is not primarily to reduce the quantity of seepage but rather to control the seepage to prevent the transportation and redistribution of fines by seepage beneath and around the structure and to prevent the development of channels of concentrated seepage.

To collect the seepage which does flow beneath or around the structure, a downstream filter is provided, between the shell and the foundation, consisting of selected clean sand and gravel.

The upstream cofferdam is incorporated in the structure while the downstream cofferdam should be located below the downstream toe of the dam.

The major portion of the dam will be constructed of materials excavated from the spillway. The cemented Rhododendron formation will be placed in the shell sections, both up and downstream, with the fresh clean pervious material placed in the select pervious zone, Fig. 7. If required, bank run sand and gravel from upstream borrow areas (not yet explored) may be used. These materials will be placed in 12" loose layers and each layer compacted by approximately 6 coverages of treads of a track laying tractor weighing not less than 40, 000 lbs or its equivalent. Shell material is such that it may be placed and compacted regardless of the weather conditions.

The core or impervious section will be constructed using the residual clays stripped from the surface deposits overlying the Rhododendron formation in the spillway cut. These clays are approximately at the desired water content for compaction in the dam. If it is necessary to stockpile core material, such stockpiles must be covered or protected from infiltration of water. Excavation, stockpiling, placement and compaction may be accomplished satisfactorily only during periods when there is no percipitation, which at this location will limit the work generally to the summer and fall months.

Core material will be placed in the dam in approximately 6 inch layers and each layer compacted using 12 coverages of heavy sheepsfoot roller or its equivalent. It may be necessary to add water or dry out the material for satisfactory compaction.

Between the compacted core and the up and downstream shells a filter zone is provided. This filter will consist of a well graded clean gravelly sand and is provided as a seepage transition between the impervious core and the selected pervious portion of the shell.

On the up and downstream slope a blanket of rip rap is provided to protect the crushed and compacted Rhododendron material from weathering and wave action.

Preliminary stability analyses of the embankment as described herein have been performed. For the slopes as shown in Fig. 7 and assuming that the clay in the foundation is not continuous but consists of lenses and pockets, the factor of safety against sliding of the up or downstream slopes if greater than 1.5 for the conditions immediately following construction. Typical stability analyses are summarized in Fig. 8.

STUDIES FOR FINAL DESIGN

For the final design of the structures, the following additional explorations are considered necessary:

a) Explorations to determine the type and characteristics of the materials to be excavated from the spillway. Churn drill holes are considered satisfactory.

b) Explorations to determine the quantity of clay overlying the Rhododendron formation in the spillway. These explorations may be accomplished by auger borings. If there is an inadequate quantity of suitable clay available from required excavations, then a supplemental borrow area must be located and explored.

c) Explorations to delineate the extent of clay in the foundation and from which undisturbed samples of the clay may be obtained for laboratory testing. Church drill holes may be satisfactory although, in addition, it may be necessary to put down one or two deep test pits to examine and sample the thin clay layers at depths up to 30 feet more or less.

Following the explorations a program of laboratory tests will be required to determine the sheer strength, permeability, consolidation and classification of the various foundation and embankment soils. Based upon these tests and the explorations, the final design of foundation treatment and of the embankment may be completed.

SHANNON AND WILSON

/S/ by W. L. Shannon
WILLIAM L. SHANNON

TABLE I

SUMMARY OF TEST RESULTS ON

UNDISTURBED SAMPLES OF FOUNDATION MATERIALS

Hole No.	Sample No.	Depth ft.	Natural Water Content %	Atterberg Limits LL %	PL %	PI %	Sheer Strength (1) Tons/Sq. ft.	Classification
D-11	2	11.8	50.6					Stiff, mottled red, gray and yellow clay with occasional gravel
	3	14.9	48.9	87	43	44	0.71	Mottled red, gray and yellow clay with angular rock
	5	31.6	33.4				2.09	Rhododendron
D-12	2	24.7	30.3	84	28	56		Compact gray clayey gravel
	2	24.9	30.5	75	26	49		Stiff, mottled gray and tan fine sandy clay
	2	25.2	34.8	77	35	37	1.24	Soapy appearance, micaceous

(1) Shear strength determined by Triaxial-Quick Test, σ_3 = 2.0 Ton/sq. ft.

TABLE II

SUMMARY OF TEST RESULTS ON

SAMPLES FROM TEST PIT IN SPILLWAY AREA

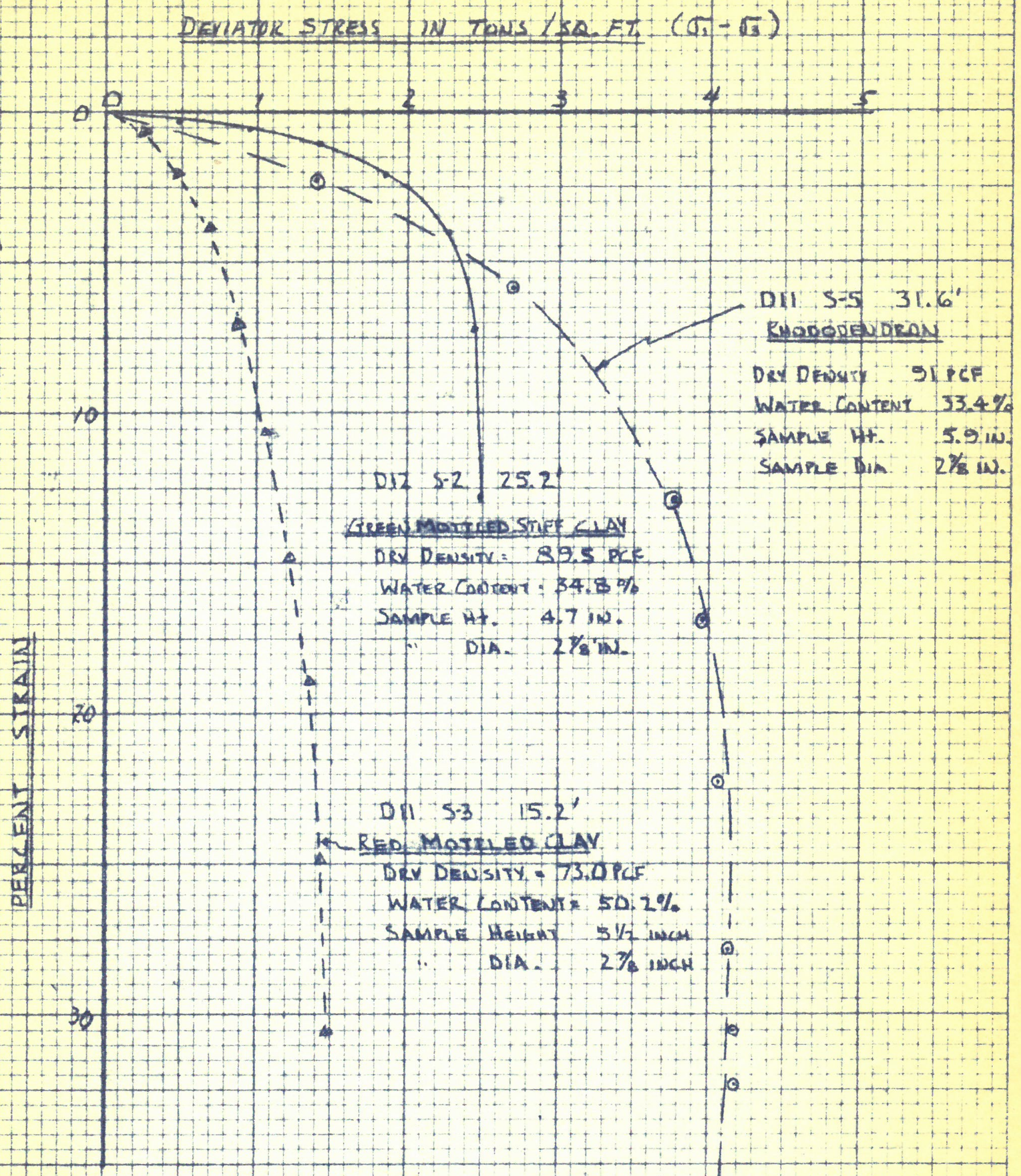
Sample No.	Chunk No.	Natural Water Content %	In-Place Dry Density PCF	Atterberg Limits LL %	PL %	PI %	Classification
21	1 of 4-A	23.4	101.0				Rhododendron
	1 of 4-B	27.7	96.0				Rhododendron
	2 of 4-A	24.5	104.0				Rhododendron
	2 of 4-B	22.2	105.0				Rhododendron
	3 of 4-A	23.6	100.7				Rhododendron
	4 of 4-A	11.7	123.2				Rhododendron
22	1 of 4-A	41.4	85.6	58	37	21	Dark and light red clay
	1 of 4-B	43.8	80.1	67	42	25	Brown, yellow and gray mottled clay
	2 of 4	44.2	83.7	70	43	27	Brown, yellow and gray mottled clay
	3 of 4-A	49.7	76.6	74	45	29	Brown, yellow and gray mottled clay
	3 of 4-B	42.5	86.4	68	42	26	Dark red clay, some light gray and brown
	4 of 4-A	38.6	66.6				Light gray, yellow and brown mottled clay
	4 of 4-B	41.0	71.0	63	38	25	Light gray, brown and dark red clay

TABLE II, cont'd -- 2

SUMMARY OF TESTS RESULTS ON

SAMPLES FROM TEST PIT IN SPILLWAY AREA

Sample No.	Chunk No.	Natural Water Content %	In-Place Dry Density PCF	Atterberg Limits LL %	PL %	PI %	Classification
23		44.5					Vane sheer 2.74 Ton/sq. ft. Residual 0.68 Ton/sq. ft.
24		46.0					Vane sheer 2.46 Ton/sq. ft. Residual 0.41 Ton/sq. ft.
25		36.9					Vane sheer 2.46 Ton/sq. ft. Residual 0.41 Ton/sq. ft.



LOWER BULLS RUN DAM

TRIAXIAL - QUICK TEST
UNDISTURBED SPECIMANS
STRESS STRAIN CURVES

CHAMBER PRESSURE = 2.0 TON/SQ.FT.

SHANNON & WILSON FEBRUARY 14, 1957

FIG. 1

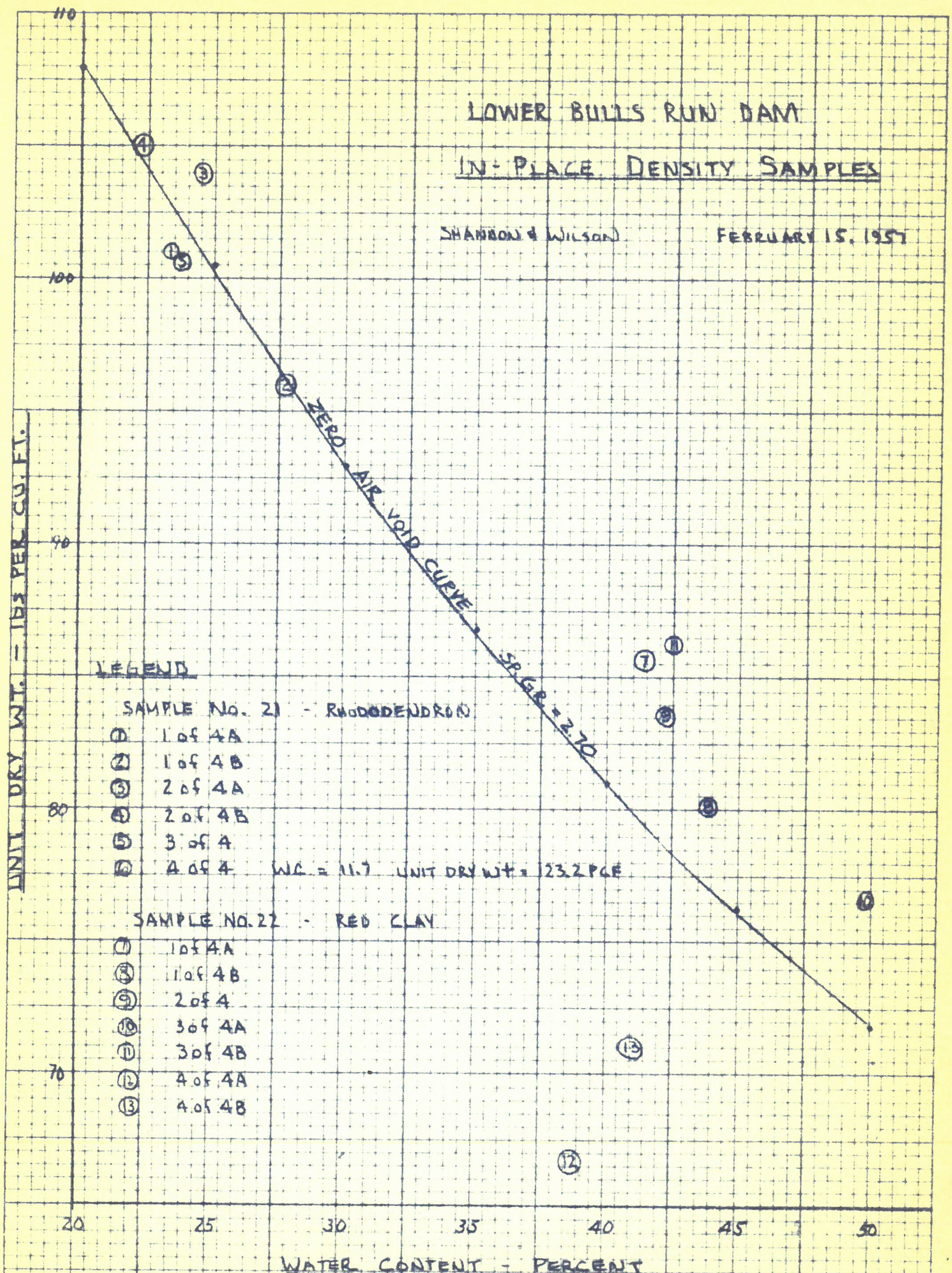

LOWER BULLS RUN DAM
IN-PLACE DENSITY SAMPLES
SHANNON & WILSON
FEBRUARY 15, 1957
ZERO AIR VOID CURVE SP. GR. = 2.70
LEGEND
SAMPLE NO. 21 - RHODODENDRON
① 1 of 4A
② 1 of 4B
③ 2 of 4A
④ 2 of 4B
⑤ 3 of 4
⑥ 4 of 4 WC = 11.7 UNIT DRY WT = 123.2 PCF
SAMPLE NO. 22 - RED CLAY
⑦ 1 of 4A
⑧ 1 of 4B
⑨ 2 of 4
⑩ 3 of 4A
⑪ 3 of 4B
⑫ 4 of 4A
⑬ 4 of 4B
UNIT DRY WT. - LBS PER CU. FT.
110
100
90
80
70
WATER CONTENT - PERCENT
20
25
30
35
40
45
50

FIG. 2

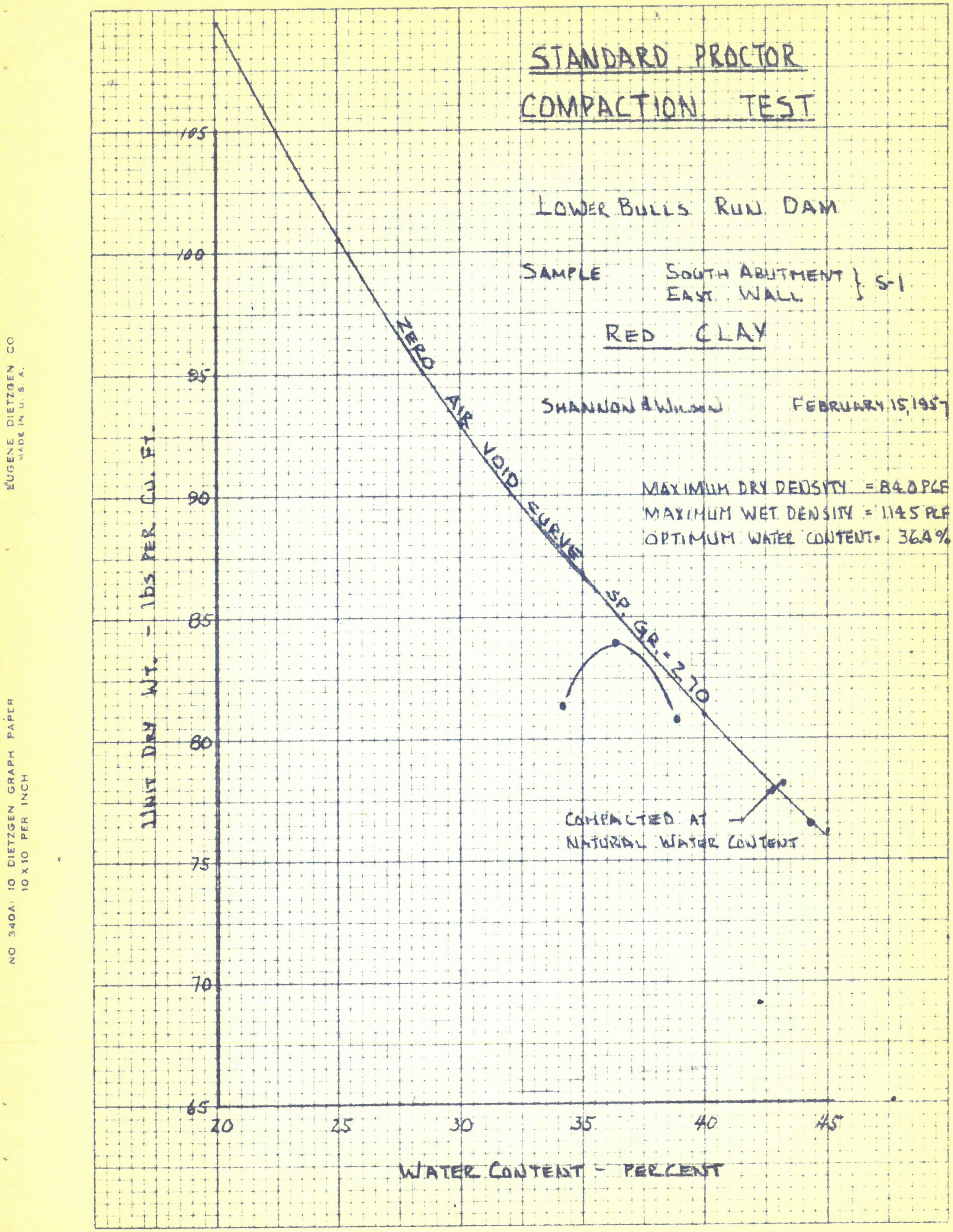

STANDARD PROCTOR
COMPACTION TEST
LOWER BULLS RUN DAM
SAMPLE SOUTH ABUTMENT EAST WALL } S-1
RED CLAY
SHANNON & WILSON FEBRUARY 15, 1957
MAXIMUM DRY DENSITY = 84.0 PCF
MAXIMUM WET DENSITY = 114.5 PCF
OPTIMUM WATER CONTENT = 36.4%
ZERO AIR VOID CURVE SP. GR. = 2.70
COMPACTED AT NATURAL WATER CONTENT
Unit Dry Wt. - lbs PER Cu. Ft.
WATER CONTENT - PERCENT
65
70
75
80
85
90
95
100
105
20
25
30
35
40
45
NO 340A1 10 DIETZGEN GRAPH PAPER 10 X 10 PER INCH
EUGENE DIETZGEN CO MADE IN U. S. A.

FIG. 3

STANDARD PROCTOR
COMPACTION TEST

SHANNON & WILSON

LOWER BULLS RUN DAM

RHODODENDRON SAMPLE

NOTE: SAMPLE CRUSHED TO MINUS 1 INCH BEFORE COMPACTION.

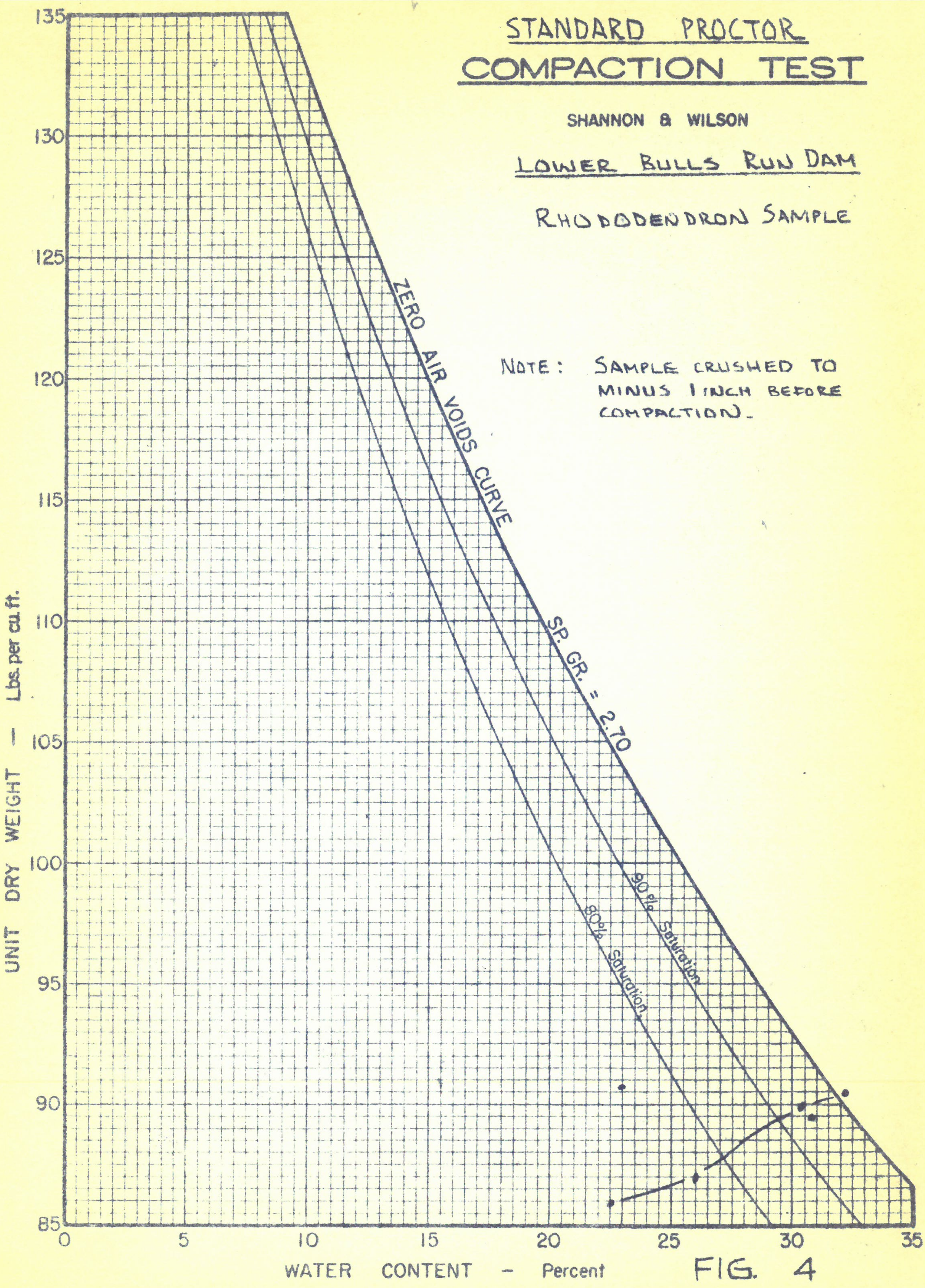
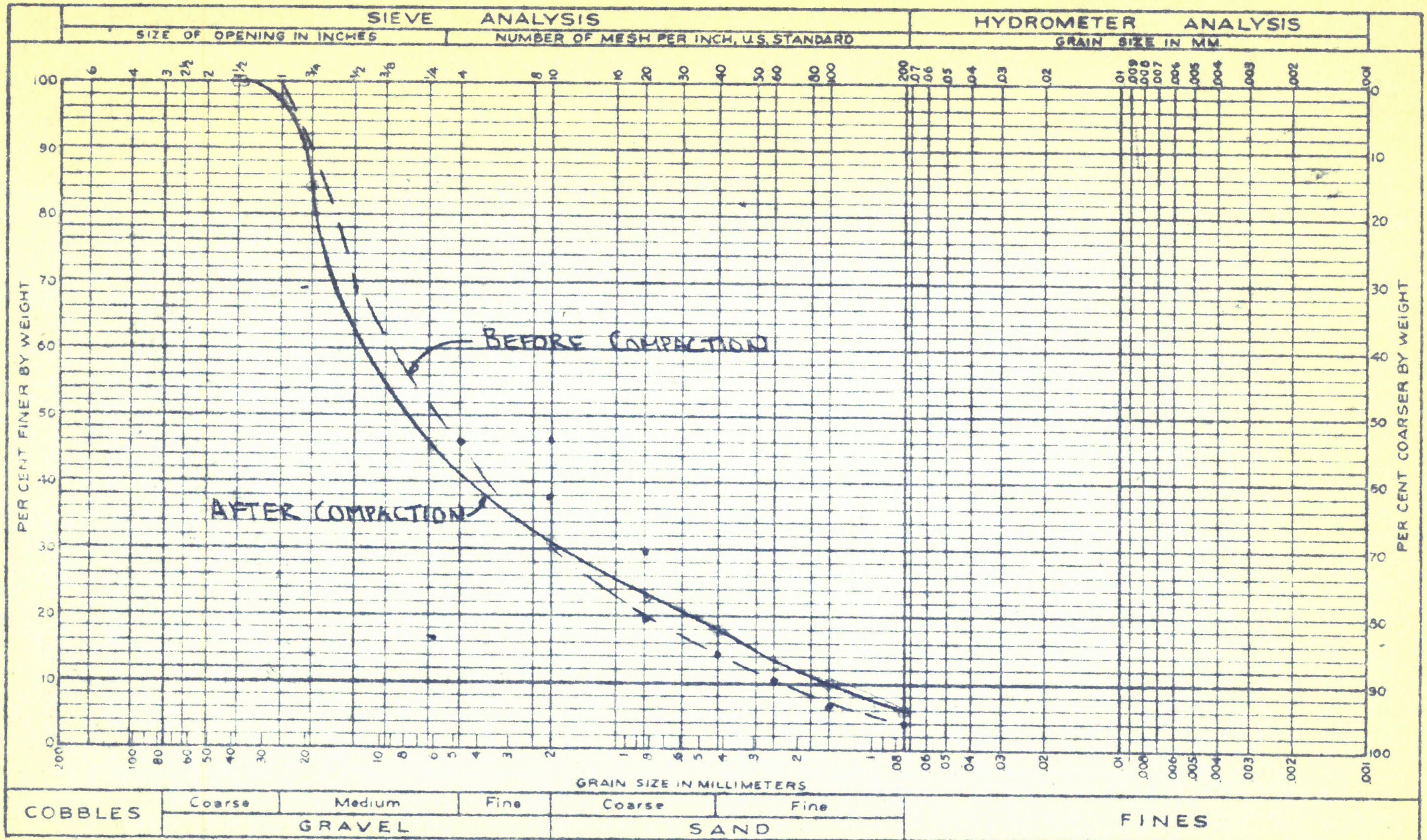


FIG. 4



SAMPLE No.	DESCRIPTION	NAT. W.C.	LL	PL	PI	SP. GR.
S-3 S-4 S-6 S-7	Combined Rhododendron					
	Note: Chunk sample crushed to minus 1 inch before grain-size analysis was run.					

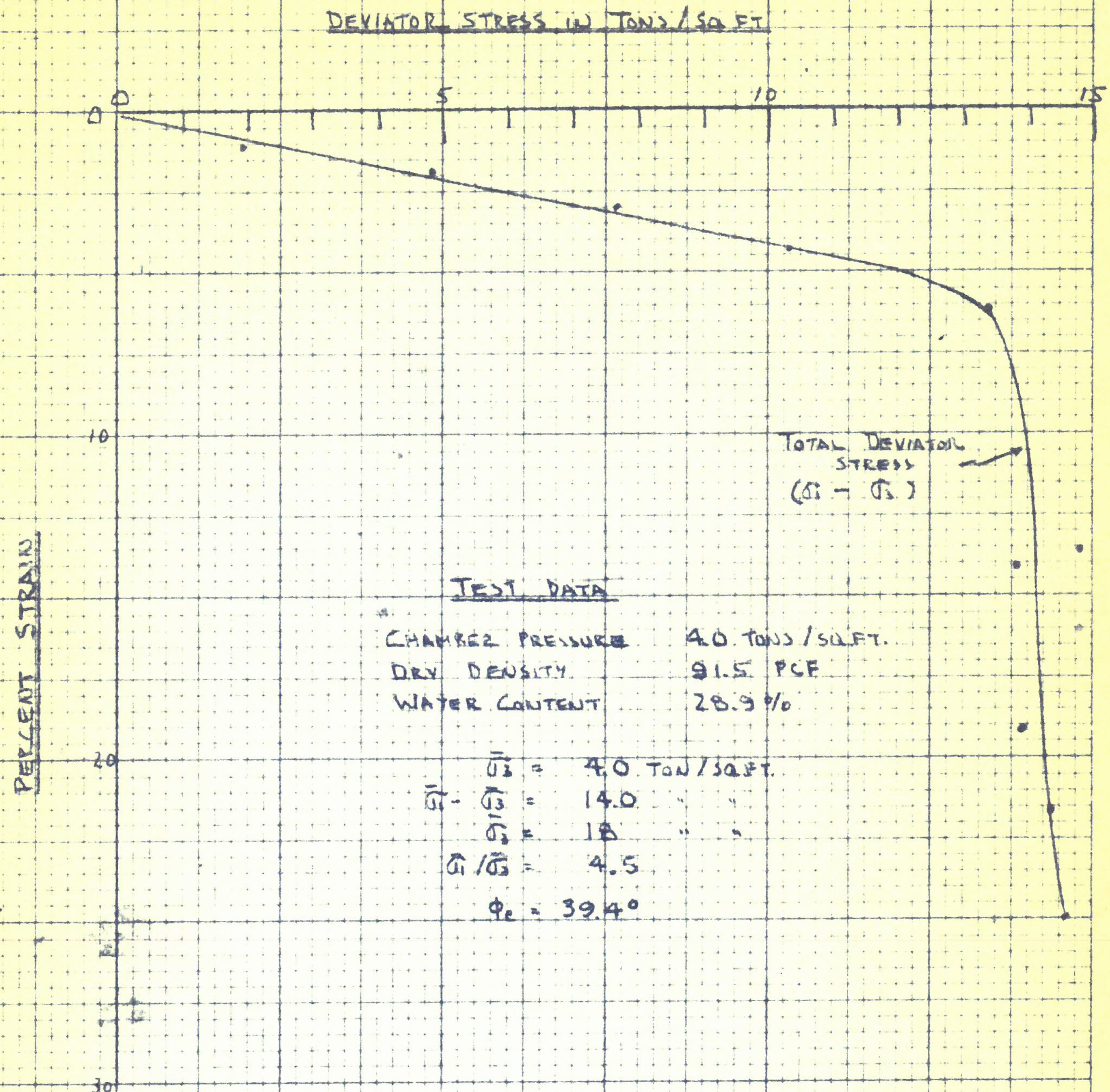
SUMMARY OF CLASSIFICATION TESTS

Lower Bulls Run Dam

Rhododendron Compaction Sample

February 14, 1957

SHANNON AND WILSON
Soil Mechanics & Foundation Engineers



TEST DATA

CHAMBER PRESSURE	4.0 TONS / SQ. FT.
DRY DENSITY	91.5 PCF
WATER CONTENT	28.9 %

$\bar{\sigma}_3$ = 4.0 TON / SQ. FT.

$\bar{\sigma}_1 - \bar{\sigma}_3$ = 14.0 " "

$\bar{\sigma}_1$ = 18 " "

$\bar{\sigma}_1 / \bar{\sigma}_3$ = 4.5

ϕ_e = 39.4°

LOWER BULLS RUN DAM

TRIAXIAL - SLOW TEST

CRUSHED AND COMPACTED RHODODENDRON

SHANNON & WILSON FEBRUARY 15, 1957

FIG. 6