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UNDERGROUND HYDROELECTRIC PUMPED STORAGE

An Evaluation of the Concept

CHAS. T. MAIN, INC.
Prudential Center Boston, MA 02199

NOVEMBER 1978

FINAL REPORT

Prepared for:

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
ENGINEERING AND RESEARCH CENTER
Denver, Colorado 80225

DEPARTMENT OF ENERGY
ADVANCED PHYSICAL METHODS BRANCH
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Washington, D.C. 20545

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UNDERGROUND HYDROELECTRIC PUMPED STORAGE
AN EVALUATION OF THE CONCEPT

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

This report is intended as a contribution to the Bureau of Reclamation's Underground Hydroelectric Pumped Storage (UHPS) Program. Its objective is to enhance the state-of-the-art through research and developmental work. It is directed to the review of the present state-of-the-art, evaluation of the technical feasibility and economic viability of UHPS, identification for further research, and recommendation for a continuing program of development.

As a backdrop, there was undertaken an in-depth review of published material on UHPS. This reveals that, although the principles of pumped storage have been long known, attention to UHPS has come to focus only within the last ten years. In the latter three years major contributions surfaced in four significant studies. These studies, although oriented to different objectives, have commonalities, based on assumptions of competent rock encasement, enabling concurrence in technical feasibility and economic viability.

Criteria of 2000 MW capacity, 1200 m/(4000 ft.) head, and 10 hour storage was utilized for the analysis in this report. This resulted in three potential schemes: two one-drop schemes, one based on multi-stage reversible units, and the second on tandem units with separate multi-stage pump and Pelton impulse turbine. (Plate IV-1). The third scheme is of the two-drop type predicated on the use of an intermediate powerhouse and small intermediate reservoir at approximately half depth. This scheme utilizes single stage reversible pump/turbines.

Cost range for the three schemes ranged from \$318/kW to \$346/kW (excluding AFDC and escalation). Total estimated cost of the multi-stage reversible unit scheme, the most advantageous, is \$636,500,000 (at 1977 price level) including contingencies, engineering, supervision and overhead, but excluding allowance for funds during construction (AFDC) and escalation.

Suitable sites are available within economical distances of most of the electric systems of the country, although they are restricted by essential underground rock conditions to zones of favorable geology and generation mix components of the systems.

Underground construction involved introduces no new technology, experience in this type of work being well defined. The large volume of rock to be removed - 7,400,000 m^3 (9,700,000 c.y.) - lengthens the construction period of conventional pumped storage by 3 to 3½ years, with a significant impact on AFDC.

There is precedent in equipment development for all schemes with the exception of the deep multi-stage reversible units of the size recommended herein (Scheme I). Although the head introduces no significant problem, these units are presently limited to 140 MW as compared to recommended units of 333 MW. European manufacturers, however, have given assurance that these units can be developed if actual demand exists.

Results of the system studies and economic analysis show that UHPS offers substantial savings in investment cost over coal-fired cycling plants and substantial savings in system production costs over gas turbines. The total present worth of system operation cost, plus alternative unit investment cost, for the 50-year life of the UHPS plant favors UHPS. While UHPS is more economical than coal-fired cycling units in both scenario systems, the economy of UHPS over gas turbines is only marginal in systems with small proportion of gas turbines but much more so in systems having a greater proportion of gas turbines.

Energy consumed during construction is estimated to be 2,204 GWh for UHPS vs. 4,202 GWh for four 500 MW coal-fired cycling plants.

Addressing the environmental factors, those of a socio-economic nature are those associated with any major project: housing, services, and boom conditions. Properly planned for in the design stage, they should be controlled. Natural environmental conditions at the upper reservoir will be impacted, but are subject to mitigation. Major project impacts are disposal of large quantities of rock excavation; rock body heat at lower reservoir and transfer to the upper reservoir through the water column during cycling; water quality impact by mineralization; and potential increased nutrient levels in the reservoirs. The construction of a man-made dedicated upper reservoir will significantly reduce the impact of these negative factors to acceptable levels.

The combination of an underground nuclear power plant and UHPS was studied. Although technically feasible, an overall evaluation weighs against it and the combination is not recommended.

UHPS compares favorably with conventional pumped storage. Construction cost is essentially the same, in the low to middle $300/KW. O&M costs are essentially the same with a possible favoritism to UHPS.

UHPS should appeal to a utility company in lieu of conventional pumped storage in that it minimizes plaguing and delaying site selection and acceptance problems; develops greater head and capacity; is applicable in water scarce areas; and potential location to load centers shortens transmission and costs and line losses.

The bulk of UHPS components being underground have minor environmental factors, especially where a lower surface reservoir needs to be created. This is similarly true in comparison to a CFCP where architectural aesthetic features, site beautification and/or adjunction will be required, and emission problems are a factor.

Opportunities for research are limited. Aside from normal evolutionary improvement, candidates are: in-situ rock stress levels and behavior at depths; air evacuation at the lower reservoir; heat dissipation and control; eutrophication; optimum maximum head; system simulations extended to cover additional systems, future years, and more than one increment of UHPS. Resolution of the cited problems would result in major steps in the state-of-the-art.

A program of development of UHPS, accepting the tenet that it is physically feasible and economically viable, requires the tutorial sponsorship of a Federal agency. Its purpose would be to bring to the attention of the utility companies additional in-depth technological and economical values of UHPS. This would then provide the decision-makers the capability to give due consideration to UHPS as a viable component of the generation mix.

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It is concluded that UHPS is technically feasible and economically viable under system conditions when it relegates expensive-to-run alternatives; e.g., combustion turbines to reserve status. Additionally, the inherent benefits may be noted of all pumped storage of rapid load response, emergency relief capacity, economic improvement as pumping energy sources improve, and capacity for voltage regulation.

1.0 SUMMARY

1.1 Introduction

The objectives of this study are to investigate the state-of-the-art of underground hydroelectric pumped storage (UHPS), to evaluate its practical feasibility and relative economic viability, to identify needs for further technological and economic research, and to formulate a continuing program of development.

1.2 State-of-the Art

The subject of UHPS has been under consideration for a period approximating 10 years. During the first seven years, the output was in the nature of individual papers of a pioneering nature aimed at the potentialities of UHPS. The latter three years of this 10-year period introduced sponsored studies by consultant firms (see Table II-1) and represents the more current thinking on UHPS.

A review of these major studies leads to the following conclusions:

a. Recommended installations are of 1000-2000 MW capacity, with storage for 10 hours generation, and powerhouse and underground reservoir located at depths in sound rock of 730 to 1340 m (2400 to 4400 ft.)

b. Project costs range from $250 to $310 (1976 price levels) per kW. Costs include engineering, overhead, and contingencies. AFDC and escalation not included.

c. Contingency allowances for underground and above ground civil works are the same.

d. Single drop is proposed under 900 m (3000 ft.) and two drop ("cascade") for greater depth.

e. 200 and 300 MW units should be used.

f. UHPS is technically feasible and economically viable.

1.3 Design Development

Investigation carried out in the MAIN study demonstrates that UHPS is a viable method of developing pumped storage. Three individual schemes: Scheme I using multi-stage reversible pump/turbine units with a single underground reservoir; Scheme II, a two-drop scheme utilizing single stage reversible units ("cascading") using an intermediate powerhouse reservoir with an overflow shaft to the lower reservoir; and Scheme III, a one drop scheme with tandem units, i.e., a separate impulse turbine and pump (multi-stage) aided by a small Pelton wheel (See Plates IV-1 & 6). Construction of the upper reservoir, underground reservoir(s), and powerhouse(s) present no unusual problems. Sinking of shafts is an accepted practice while heading and benching of underground structures follows conventional mining methods. The underground reservoir will be at a depth of 1200 m (4000 ft.). Underground rock excavation totals 7,400,000 m^3 (9,700,000 c.y.). Suitable rock excavation material will constitute the embankment section of the upper reservoir dike. Pump/turbine equipment for Schemes II and III is currently available while the equipment for Scheme I is not. Existing multi-stage reversible units are presently limited to normally 140 MW although the head presents no problems. Contacts with European manufacturers indicate that equipment modifications can be made to accommodate the design requirements of Scheme I.

1

1.4 Construction Period

It is estimated that for a capacity of 2000 MW, 10 hours storage and 1200 m (4000 ft.) head, the construction period from construction contract award to testing and commercial operation for Schemes I, II, and III is approximately 7½ years. Increasing the head to 1500 m (5000 ft.), while holding the same capacity and storage as above, increases the construction period by six (6) months. Reduction of the head alone to 900 m (3000 ft.) increases the construction period by 2 years (increased underground storage reservoir). Maintaining the basic criteria but increasing the number of units from 6 to 8 adds 2-3/4 years to the base. Holding the 1200 m (4000 ft) head and storage of 10 hours but reducing the capacity to 1300 MW and using four units reduces the construction period 6 months.

1.5 Relative Economic Viability

UHPS is a competitive method for pumped storage generation. Cost estimates for the three UHPS schemes indicate per kilowatt costs of: Scheme I - $318; Scheme II - $329; Scheme III - $346 (excluding AFDC and escalation). These prices are as of January 1977. A review of Hydroelectric Plant Construction Cost and Annual Production Expenses, 1974, Federal Energy Regulatory Commission, and other sources establish per kilowatt costs adjusted to January 1977, for large capacity conventional pumped storage plants of recent construction as follows: Ludington, Michigan - $269; Bath County, Virginia - $399; Bear Swamp, Massachusetts - $230 (utilizing an existing lower reservoir); Boyd County, Nebraska - $386.

These costs do not include AFDC which can amount to 25 to 35 percent of construction costs.

Operationally UHPS is equivalent to conventional pumped storage. It normally has a position on the load curve which will perforce be dictated by the generation mix of the system and the cost of operating each unit that is available.

(Comparisons have been made with the costs of coal-fired cycling plants (CFCP) of 500 MW and gas turbines. CFCP has been chosen for comparison as it realized the lowest electrical cost between 23% and 35% capacity factor. Further considerations were that a 450/500 MW unit appears compatible with the needs of a large number of utilities, is within the "state-of-the-art" for boiler and turbine generation manufacturers, is suitable for burning low sulphur western coal or lignite, and incorporates special design features for cycling and quick starting. The capital cost per kilowatt is $400/600 (1977 price level). This figure was developed utilizing the base of assumed installation in a mid-western area west of the Mississippi. This price may escalate in higher priced labor areas and areas in which economic low sulphur coal is not as readily available.

1.6 Total Energy

The total energy requirements for the construction of a 2000 MW UHPS Project and a comparison alternative of 4-500 MW units coal-fired-cycling-plant have been computed and set forth in Chapter 7.

1

1.6.1 Construction Energy

UHPS - 2,203,830,000 KWh
CFCP - 4,201,759,000 KWh

1.6.2 Energy During Operations

The two systems (EPRI) used represent differing load and generation mixes in which Scenario D has a relatively smaller preparation of low cost base generation than Scenario A.

UHPS (50 yr)	Pumping	Generating
Scenario A	82,944 GWh	58,045 GWh
Scenario D	74,497 GWh	51,884 GWh

CFCP (50 yr.)	Generating
Scenario A	505,111 GWh
Scenario D	591,983 GWh

The larger amount of energy generated by CFCP compared to UHPS is due to the lower position of these units on the load duration curve.

Note: 50 yrs. of operation have been used for comparison. Actual life of CFCP is 30/35 years which is equally true of gas turbines. UHPS has an economic life of 50 years with physical potential of a longer period.

The time required to recover UHPS construction energy expenditures for the total, both construction operations and equipment and materials, considering displacement of inefficient thermal sources would be 6.6 months. For construction operation alone, i.e. construction equipment operation alone, it would be 3.1 months.

1.7 Results of the Simulated Power Systems Economic Comparison

Results of the system studies and economic analysis show that UHPS offers substantial savings in investment cost over coal-fired cycling units, and substantial savings in system production cost over gas turbines. The total present worth of system operation cost plus alternative unit investment cost, for the 50 year life of the UHPS plant, for both Scenarios, are shown below:

SCENARIO A	Total Present Worth ($ Millions)	Differential Present Worth ($ Millions)
UHPS	51922.7	0.0
Coal Cycling	54036.0	2383.3
Gas Turbines	51931.7	9.0
SCENARIO D		
UHPS (6 hr. reservoir)	35344.7	0.0
Coal Cycling	36900.8	1556.1
Gas Turbines	36011.4	666.7

It is seen that while UHPS is more economical than coal cycling units in both systems, the economy of UHPS over gas turbines differs greatly depending upon the system.

1.8 Combination of Underground Nuclear Plant and UHPS

Although such a combination is technically feasible it is not recommended. There are positive factors but the negative ones: cost, longer construction period, operational penalties, and potential impact on UHPS resulting from nuclear accidents, are overriding.

1.9 Environmental Factors

UHPS has definite positive environmental benefits over a conventional pumped storage plant. Encasing the lower reservoir and plant underground frees them from problems of surface visibility and siting, thus making the configuration more compatible with present environmental philosophies. The benefits, especially in cases normally requiring creation of a lower reservoir, are:

a. Elimination of lower reservoir dam and probable fish ladder (costly).

b. Reduced timber cutting.

c. Lesser impact on deer yards.

d. Elimination of stream vs. flat-water fishing controversies.

e. Simplified structure design minimizing aesthetic treatment.

f. Lesser drought impacts.

These collectively have significant monetary gains as well as potential impairment to the natural environs. The preparation of the Environmental Impact Statement is simplified.

Certain disadvantages do exist:

a. Disposal of large quantities of rock

b. Mineralization of water

c. Transfer of lower rock body heat to upper reservoir during pumping.

d. Potential eutrophication in reservoirs. These can be minimized, in the latter three items, by use of a dedicated upper reservoir.

1.10. Transmission

Precise comments on transmission are difficult as they would be dependent on the project siting and existing system. However, in general, the capability of UHPS to be located closer to load centers should reflect in favor of UHPS compared to conventional pumped storage. This advantage may not result in comparison to thermal plants.

1.11 Technological and Economic Research

Due to the marked similarity of UHPS to conventional pumped storage, both physical and operational, there are limited opportunities for research. Effort can be directed to studies on in-situ stress levels at the great rock depth associated with UHPS. To date available techniques have been performed only to comparatively shallow depth of several hundred meters. This data is an important element to rock cavern support.

Other opportunities are air evacuation at lower levels, heat dissipation and control, eutrophication, optimum maximum head, and system simulations analyses.

The greatest research opportunity is in pump/turbine development. Investigations herein show that the use of a one drop multi-stage reversible pump/turbine unit is preferred. Design principles of this unit are known to manufacturers, primarily European, but they have not as yet been placed into practice for the unit capacity recommended (333 MW) in this report. Summarily the need exists for larger capacity units. However, manufacturers say that there is no problem in attaining the requisite modifications, if there is an actual commercial need.

1

1.12 Continuing Program of Development

Aside from evolutionary improvements that always accompany an engineering scheme of merit is the need for an educational program for the Electric Generating Industry. Included in the subject matter should be component technology, geological requirements, costs, system integration, environmental acceptance, economics, and lack of seasonal fluctuation in generation fuel (water). Promotion of UHPS should be concentrated in those areas of the country where suitable geologic opportunities exist since potential sites are not indigenous to all regions. (See Plate III-1).

Utilities, and even governments, should become informed of the inherent advantages proferred by UHPS or it will remain an untried engineering theory. All engineering media and associations should be informed of the details and potentials of UHPS.

1.13 Key Numbers and Facts (UHPS)

$/kW - $315

$/kWH - $14 (1200m)

mils/kWH - 15 mils

Round trip efficiency - 67-75%

2.0 REVIEW AND EVALUATION OF PREVIOUS STUDIES

2.1 General

This section presents the results of a literature search and review of studies related to the concept of underground Hydroelectric Pumped Storage (UHPS). The evaluation of these studies capsulizes the state-of-the-art of UHPS and provides the backdrop and guidance essential to the study herein.

2.2 Procedure

Serious discussions of UHPS began about 10 years ago. However, it has only been within the last few years that important work has materialized. Four recent studies represent the current thinking on UHPS. It is noted that no actual experience is available inasmuch as no UHPS has as yet been built. Significant features, for comparative purposes have been extracted and herein highlighted. A brief summary and comparison of the four studies is set forth on Table II-1. Other references which have been studied are listed in Table II-2. (These tables are found at the end of this chapter.)

2.3 Findings

Basic factors common to the four studies of UHPS may be classified as: geology, pump/turbine technology, cost, and economic viability. Comments on the treatment of these aspects in the four referenced studies follow.

2.3.1 Geology

The major geologic criteria, generally speaking, follows the same pattern in all studies: need for massive crystalline (igneous or metamorphic) rocks, preferably granitic, thick sedimentary beds with minimal jointing (preferably limestone or dolomite); no tectonic stresses, and no high seismic risk. The United States maps in some of the reports depicting suitable and non-suitable areas for siting UHPS are in general agreement and satisfactorily reflect available information. A modified map of the Acres Study (Study No. 3) is reproduced as PLATE III-1.

Study No. 1 stated that a sound stratum of 60 m (200 ft.) thick is adequate for the major underground structures. This requirement appears to be inadequate as 100 m (300 ft.) is required merely to encompass the excavation extending from the lowest point in the powerhouse to the highest point in the draft tube gate gallery (see PLATE IV-1).

Study No. 3 includes a detailed description of a system for the engineering classification of rock masses for the design of tunnel supports. The practicality of exploring deep rock in the detail essential to apply this system to feasibility studies is questionable. Studies of this level should, and can safely, rely on general geologic data and rock characteristics measureable in deep bore holes up to 1340 m (4400 ft.).

2.3.2 Pump/Turbine Technology

It is the consensus of the studies that the limitation on the maximum operating head for a one drop UHPS plant with single stage reversible units, through the 1980's, due to available equipment, will be in the magnitude of 762 m (2500 ft.). It is axiomatic that to optimize UHPS projects the head should be at the maximum dictated by pump/turbine technology. Manufacturers are sure that, if actual conditions demand, equipment can be developed to satisfy a need ranging between 914 m (3000 ft.) and 1372 m (4500 ft.).

2

It is MAIN's opinion that the most economical and reliable pump/turbine for UHPS operation is the single drop reversible unit. However, it is presently indicated that this unit will not exceed 765 m (2500 ft.). For greater depths, in the range of 914-1372 m (3000 to 4500 ft.) the arrangement can be accomplished by adopting a two drop scheme. Two other alternatives are: the recently developed multi-stage reversible pump/turbine; and tandem units. The latter have been successfully employed in Europe for years, with a multi-stage pump located on a common shaft with a reversible generator/motor and a Pelton Impulse Turbine. These latter units are efficient, start quickly, and their changeover time between pumping and generating is short.

Reliable multi-stage reversible units in the 250 MW size and 1200 m (4000 ft.) head range are expected to be available for purchase by 1981-1982.

2.3.3 <u>Estimated Project Costs</u>

The reviewed studies conclude that large (2000 MW, 10 hour) UHPS projects, with favorable geologic conditions, can be built within the range of \$250 to \$300/kW. (The present report basically supports this conclusion.) The cited figures are based on mid-1976 prices. It may be noted that the Mt. Hope (New Jersey) project in its application for FERC license carries a cost of $230/kW. This is attributable to unusually favorable local conditions which induce a marked reduction in the lower reservoir cost.

Underground excavation including shafts, adits, and lower reservoir represents approximately 30% of the total project costs (including contingencies but excluding interest during construction - AFDC.) It is therefore evident that unit excavation costs have significant impact on project costs. The four cited studies carry excavation prices ranging from $18 to $28/m^3 ($14 to $21/c.y.) Study No. 4 carries the highest cost of $27.6/m^3 ($21.1/c.y.) This is attributable to inclusion of 10% for rock support and a 20% overall contingency. These figures, based on mid-1976 prices compare with the developed January 1977 price in this report of $30/m^3 ($23/c.y.), which includes rock bolting, mesh, and shotcrete for total roof support plus a 25% overall contingency.

Study 4 reports the mid-1976 price for 8-250 MW pump/turbines, governors, and valves including installation and 10% contingencies at $46/kW. Design head for these units is 670 m (2200 ft.) The present study carries a comparable figure for a design head of 600 m (2000 ft.) of $40/kW.

2.3.4 Economic Viability

The economic viability of Underground Hydroelectric Pumped Storage (UHPS) has been addressed significantly in prior studies. Among these, the July 1976 report for EPRI and DOE by Public Service Electric and Gas Company (Study 2, Table II-1) establishes data representative of the U. S. electric utility industry, regardless of geographic location, as to:

1. availability of off-peak energy

2. daily, weekly and seasonal distribution of this energy

3. on-peak energy and power capacity potentially available from stored off-peak energy.

The principal findings and conclusions of the Public Service Report, relative to UHPS, are as follows:

1. Expected cost of an UHPS project - 1000 MW, 900 m (3000 ft.), 10 hour storage - (adjusted to July 1, 1976 and to include AFDC at 3.8% is $352 per kilowatt.)

2. Investment of up to $430/kW (including AFDC at 3.8%) in UHPS with 10 hour storage is justified for a system assumed as typical (all prices July 1, 1976):

a. annual UHPS generating operating time (annual generation divided by rated capacity) - 1,000 hours

b. Fossil fuel cost (gas turbines and combined cycle units) - $2.65/MBTU

c. escalation at 6%/year for all costs - plant, O&M, and fossil fuel

d. Levelized incremental cost of off-peak energy for pumping - 22 mills/kwh.

Specifics of the market capture potential for UHPS in the U.S. are included in the March, 1977 report for ANL and DOE by

Harza Engineering Company (Study 4, Table II-1). The Harza report indicates that the conditions described by Public Service Electric and Gas are typical of the U.S., and thus favorable for UHPS. These conditions are not met or exceeded in two regions: the Southcentral U. S. including Texas, Oklahoma, Kansas, Arkansas and Louisiana and adjacent parts of New Mexico, Missouri and Mississippi which make up the Southwest Power Pool (SPP) and the Electric Reliability Council of Texas (ERCOT); and the 11 western states comprising the U.S. part of the Western Systems Coordinating Council (WSCC) (see PLATE II-1). In the first (SPP), Harza predicts that there will be no coal-fired or nuclear steam available for pumping until after 2005 because of the present preponderance in the area of oil and gas fired base load units. In the WSCC region, Harza predicts that not until after 1995 will there have been full exploitation of the potential for normal pumped storage and conventional hydroelectric projects that are more feasible than UHPS.

Harza predictions of the market potential of UHPS (adjusted by MAIN to correspond with minor differences in regional outlines) are as follows:

	THOUSAND MW			
	1995		2005	
Region of United States	Peak Demand	Potential	Peak Demand	UHPS Potential
Northeast	220	8	400	27
East Central	217	23	393	45
West Central	48	2	92	6
West	181	0	366	6
South Central	224	0	479	0
Southeast	260	3	440	6
	1,150	36	2,170	90

Since the breakeven cost per kilowatt necessary for UHPS to be competitive with its most economical alternative is not stated in their report, it is assumed that Harza's conclusions as to the market potential for UHPS apply to 2,000 MW plants with 10 hour storage costing under $308 per kilowatt to build, at mid-1976 prices excluding AFDC.

2

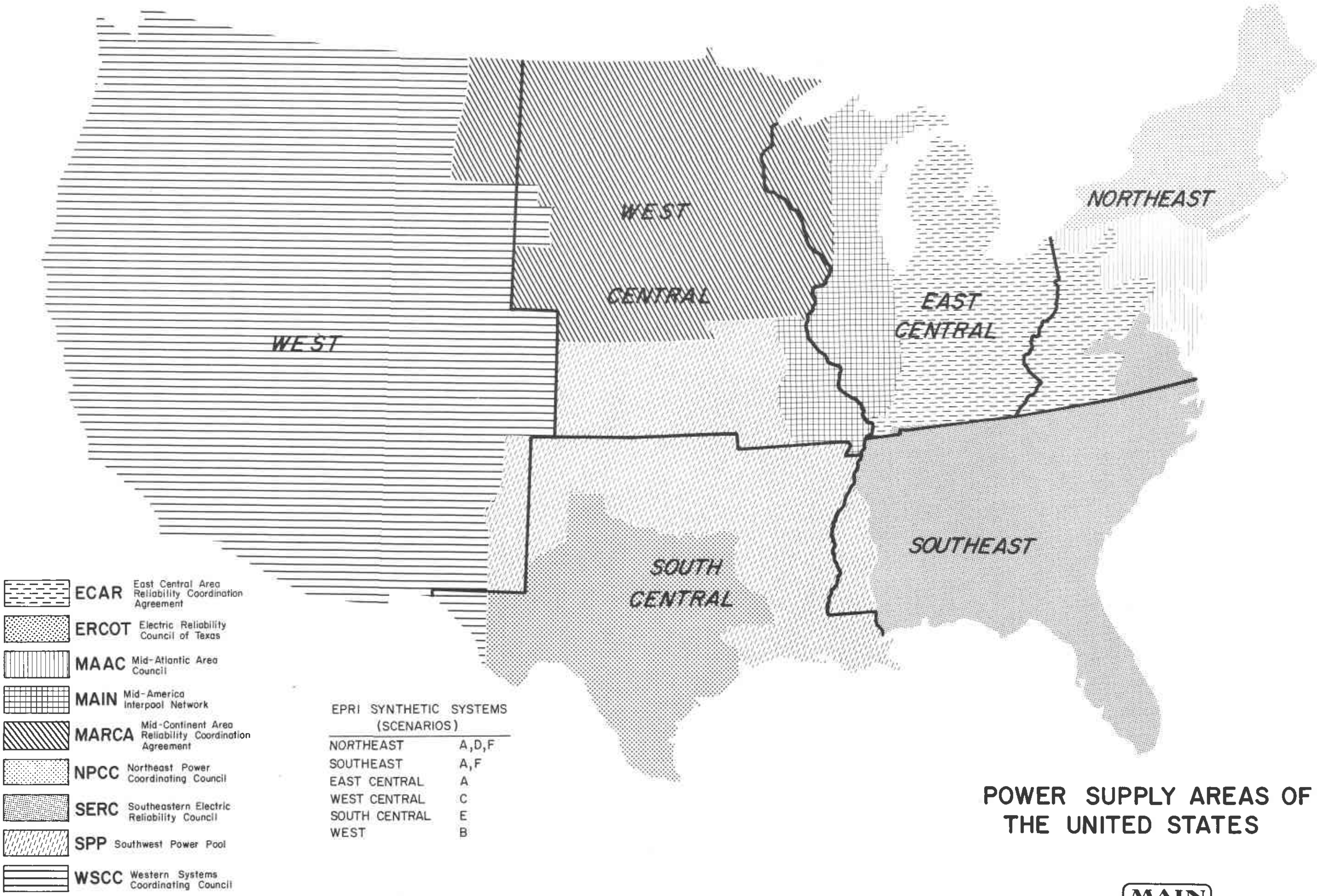
2.3.5 Specific Comments on Four (4) Studies

Although there is considerable agreement in the referenced studies there are some significant differences of opinion on certain facets. These specifics and other comments pertinent to UHPS are here extracted:

a. Study No. 4 affirms that "The most economical concept is a two drop project developing 670 m (2200 ft.) in each drop for a total project head of 1340 (4400 ft.) whereas Study No. 1 questions if there is a significant economic advantage to be gained in the adoption of heads in excess of 914 m (3000 ft.).

b. It is noted in DOE's position that in its program, under development, the maximum head which could be considered is around 730 m (2400 ft.). Presumably this is the extrapolated limit for single stage reversible pump/turbines. Incidentally, this is essentially the same as the maximum gross head for the Mt. Hope Project, New Jersey (conventional pumped storage.)

c. Comparative studies in Reference 4 for UHPS of 2000 MW capacity, 8 hour storage, and 975 m (3200 ft.) total head show a cost increase of about 13% for the one drop scheme utilizing tandem units in two equal drops. The cost comparison, however, does not recognize the possible need for a surge



EPRI SYNTHETIC SYSTEMS (SCENARIOS)	
NORTHEAST	A,D,F
SOUTHEAST	A,F
EAST CENTRAL	A
WEST CENTRAL	C
SOUTH CENTRAL	E
WEST	B

POWER SUPPLY AREAS OF THE UNITED STATES

MAIN PLATE II-1

shaft on the intermediate reservoir imposed by the intermediate powerhouse and reservoir; and operation limitations imposed by the two plant scheme - such as the automatic limitation on one plant caused by a unit outage in the other. Study 2, Table II-1 remarks that plants in series have costs and operation problems avoidable in a single drop development.

4. All four studies (Table II-1) evaluate UHPS projects of 10-hour storage. The MAIN study demonstrates that a project tailored to a particular electric utility system may well have substantially less storage and correspondingly lower cost.

5. The special financial contingency associated with extensive rock excavation at great depths for the lower reservoir is treated differently in the four studies on Table II-1.

6. The matter of contingencies, even with good rock information, deserves as much in-depth evaluation as possible. In the Mt. Hope application of FERC for licensing a proviso was included: "However, the possibility exists that actual construction and purchasing experience may prove that the costs are too great to justify the completion of the project. Should such eventuality occur, the applicant will attempt to reduce the scale of the project with regard to either the storage or capacity, or both, so as to result in an operable facility which approaches, as closely as possible, the intended goals."

7. All four (4) studies concurred that UHPS will take 2-3 years longer for construction than conventional pumped storage.

2.4 Summary

The existing studies and reports for UHPS recommend installations of 1000 - 2000 MW capacity, 10 hour storage, with the lower reservoir located at depths of 732-1240 m (2400 to 4400 ft.).

Cost in $/kW range from $250 to $310 (exclusive of escalation and AFDC.)

There was unanimity of opinion on the need for competent rock encasement.

The four studies referenced were undertaken for differing purposes - see Table II-1 under "Remarks" column - but did have sufficient commonalities to permit concurrence in the feasibility and viability of UHPS.

UNITED STATES DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION (USBR)
UNITED STATES DEPARTMENT OF ENERGY (DOE)

UNDERGROUND HYDROELECTRIC PUMPED STORAGE (UHPS)
COMPARATIVE REVIEW OF RECENT STUDIES

NOVEMBER 1978

NUMBER	TITLE	DATE	PREPARED BY	SPONSORED BY	PREFERRED SCHEME	PREFERRED TYPE OF EQUIPMENT	ESTIMATED COST $/kW	LOWER RESERVOIR EXCAVATION COST $/m³ ($/cy)	ALLOWANCE FOR CIVIL WORKS CONTINGENCIES	CONSTRUCTION SCHEDULE REMARKS	MAJOR GEOLOGIC CRITERIA	MINIMUM GEOLOGIC DATA REQUIRED	PUMPING CYCLE EFFICIENCY	PRINCIPAL PURPOSE
1	UNDERGROUND PUMPED STORAGE. RESEARCH PRIORITIES.	APRIL 1976	ACRES AMERICAN INCORPORATED	ELECTRIC POWER RESEARCH INSTITUTE (EPRI)	INDIRECTLY SUGGESTED ONE OR TWO DROPS, APPROX. 900 m (3000 FT) HEAD	200 MW UNITS: AT 700 m (2300 FT) SINGLE STAGE RUNNER REVERSIBLE AND AT 1000 m (3300 FT) MULTISTAGE RUNNER, REVERSIBLE	300 FOR 1000 MW AT 900 m (3000 FT) AND 10 HR STORAGE	19.7[1] (15) TO 23.6 (18)[1]	AMOUNT NOT KNOWN	TOTAL CONSTRUCTION SCHEDULE INCREASES APPROX 2 YEARS AS THE DEPTH INCREASES FROM 610 m (2000 FT) TO 1220 m (4000 FT)	COMPETENT STRATUM APPROX 60 m (200 FT) THICK	- CONFIRMATION OF STRATIGRAPHIC PROJECTIONS - WATER LEVELS - JOINTING, DISCONTINUITIES	-	TO IDENTIFY PARTICULAR ASPECTS REQUIRING DETAILED EXAMINATION DURING A SUBSEQUENT COMPREHENSIVE PRELIMINARY DESIGN PHASE
2	AN ASSESSMENT OF ENERGY STORAGE SYSTEMS SUITABLE FOR USE BY ELECTRIC UTILITIES.	JULY 1976	PUBLIC SERVICE ELECTRIC AND GAS COMPANY NEWARK, NEW JERSEY	EPRI, ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION (NOW DOE)	CONSIDERED: - UP TO 765 m (2500 FT) FOR SINGLE STAGE REVERSIBLE UNITS. - ABOUT 1070 m (3500 FT) FOR TWO PLANTS IN SERIES	SINGLE STAGE REVERSIBLE UNITS OF ABOUT 300 MW	≤ 290 FOR 10 HR STORAGE	18.3[1] (14) TO 22.3 (17)[1]	ABOUT 12.5%	- SUGGESTED SPEEDY LOWER RESERVOIR EXCAVATION TO REDUCE THE INTEREST DURING CONSTRUCTION	- DETERMINE FIRST TOP OF PRECAMBRIAN ROCK PREFERRED ROCKS: UNDERFORMED GRANITE - NO RESIDUAL TECTONIC STRESSES	-	70 TO 75%	TO PROVIDE THE REQUIRED DATA TO ESTABLISH RESEARCH AND DEVELOPMENT PRIORITIES FOR ENERGY STORAGE TECHNOLOGY
3	SITING OPPORTUNITIES IN THE U.S. FOR COMPRESSED AIR AND UNDERGROUND PUMPED HYDRO ENERGY STORAGE FACILITIES	DECEMBER 1976	ACRES AMERICAN INCORPORATED	ARGONNE NATIONAL LABORATORY (ANL) DOE	IN ECONOMIC COMPUTATIONS ASSUMED 200 MW PLANT, 10 HR STORAGE 1070 m (3500 FT) HEAD	-	APPROX 230	- APPROX 19.7 (15) IN COMPETENT ROCK UP TO 66 (50) UNDER ADVERSE CONDITIONS	AMOUNT NOT KNOWN	-	- CHAMBER STABILITY BASED ON BARTON'S CRITERIA (Q)	ROCK MINEABILITY & STABILITY. ROCK MASS PERMEABILITY. EXISTING GROUND WATER REGIME. LOCAL & REGIONAL ROCK STRUCTURE. IN-SITU STRESSES	-	TO CATEGORIZE THE GEOLOGY OF THE CONTINENTAL UNITED STATES IN ACCORDANCE WITH THE POTENTIAL FOR THE SITING OF COMPRESSED AIR ENERGY STORAGE (CAES) AND UHPS
4	UNDERGROUND PUMPED HYDRO STORAGE AND COMPRESSED AIR ENERGY STORAGE. AN ANALYSIS OF REGIONAL MARKETS AND DEVELOPMENT POTENTIAL	MARCH 1977	HARZA ENGINEERING COMPANY	(ANL) DOE	TWO DROP SCHEME. TOTAL HEAD 1340 m (4400 FT) 2000 MW, 6 TO 10 HR STORAGE	250 MW SINGLE STAGE REVERSIBLE UNITS AT 670 m (2200 FT) HEAD	252 TO 308 (2000 MW 10 HR STORAGE)	24.1[2] (18.4) TO 27.6[2] (21.1)	20%	TOTAL TIME 12 YEARS OF WHICH 6½ YEARS ARE CONSTRUCTION TIME - NO ADDITIONAL CONSTRUCTION TIME FOR REGION IV WITH POOR GEOLOGIC CONDITIONS FOR SHAFTS	- MASSIVE CRYSTALLINE IGNEOUS OR METAMORPHIC ROCKS - MASSIVE LIMESTONE OR DOLOMITE	UNFAVORABLE AREAS: - UNSUITABLE SEDIMENTARY ROCKS - COMPLEX GEOLOGIC STRUCTURES - HIGH SEISMIC RISK - EXTENSIVE FAULTING - VOLCANIC ROCKS	ABOUT 78%	TO IDENTIFY AND DESCRIBE REGIONAL MARKETS FOR UHPS AND CAES AND PERFORM GEOLOGIC ANALYSIS TO DETERMINE REGIONAL DEVELOPMENT POTENTIAL
	REMARKS						ALL COSTS UPDATED TO JULY 1, 1976. INCLUDES CONTINGENCIES BUT NEITHER INTEREST DURING CONSTRUCTION NOR SUBSTATION.	ALL COSTS UPDATED TO JULY 1, 1976. (1) INCLUDES CONTINGENCIES. (2) INCLUDES CONTINGENCIES, ROCK SUPPORT & DISPOSAL ON SITE.						GENERAL NOTES: THIS EXHIBIT HIGHLIGHTS THE LISTED STUDIES. COSTS HAVE BEEN INDEXED AS REQUIRED FOR PURPOSES OF COMPARISON

MAIN

TABLE II-1

<u>NOTE</u>: Table II-1 is intended to present a summary of major studies prior to this report. For this reason the findings of this report were not included thereon. Should readers so desire the following could be addended:

Title	-	Underground Hydroelectric Pumped Storage. An Evaluation of the Concept.
Date	-	June 1978
Prepared by	-	Chas. T. Main, Inc.
Sponsored by	-	Department of Interior, Bureau of Reclamation and Department of Energy, Division of Energy Storage Systems
Preferred Scheme	-	One drop arrangement with multi-stage reversible units Total head 1200 m (4000 ft.) 2000 MW, 10 hour storage
Preferred Type of Equipment	-	333 MW multi-stage reversible units at 1200 m (4000 ft.) head
Estimated Cost $/KW	-	$318
Lower Reservoir Excavation cost (1977) $m³($c.y.)	-	$24.84/m³, $19.00/c.y.
Allowance for Civil Works Contingency	-	25%
Construction Schedule remarks	-	7½ yrs. construction
Geologic Criteria	-	See Plate III-2
Pumping Cycle Efficiency	-	67-75%
Principal Purpose	-	An Evaluation of the Concept

UNDERGROUND HYDROELECTRIC PUMPED STORAGE AND ELECTRIC POWER SYSTEM GENERATION PLANNING

REFERENCES

1. ERDA "Preproposal Conference on RFP (49-18) 2159 held September 17, 1976".

2. "Application or License for Mount Hope Project" F.P.C. Series P-2753 Part I May 2, 1975.

3. "Economical and Technical Feasibility Study of Compressed Air Storage" ERDA 76-76, March 1976, prepared by Advanced Energy Programs Operations, Corporate Research and Development, General Electric Company.

4. "Hydro-Power from Underground Pumped Storage" by Frank M. Scott. ACS Div. of Fuel Chemistry Vol. 19, No. 4 (1974).

5. Proceedings of the Swedish Underground Construction Mission to the United States, October 4-15, 1976.

6. "Largest mined gas storage cavern carved from granite" ENR Jan. 1, 1976 (Mining by Fenix and Scisson Inc.).

7. "Underground reservoirs for High-head pumped storage stations" by J. G. Warnock and D. C. Willett, Water Power, March 1973.

8. "Rock Engineering for Underground Caverns" by Don D. Deere, and others, Underground Rock Chambers, Symposium held by ASCE, Arizona, Jan. 13-14, 1971.

9. "Synthetic Electric Utility Systems for Evaluating Advanced Technologies," EPRI EM 285, February 1977, prepared by Power Technologies, Incorporated.

10. "Technical Assessment Guide," August 1977, Technical Assessment Group, EPRI.

11. "Hydroelectric Power Evaluation", FERC P-35, 1968 and Supplement No. 1.

12. "Quantitative Evaluation of Operating Reserve Duty of Peak Duty Storage Plants in Power System Planning" by J. Panichelli - L. Paris - L. Salvaderi, ENEL, Rome, Reliability of Power Supply Systems, Conference Publication No. 148, 1977, The Institution of Electrical Engieers, Savoy Place, London, WC2.

3.0 TECHNOLOGICAL EVALUATION

3.1 Objectives

This section presents an evaluation of the factors essential for the development of a successful UHPS project and the determination of technological factors that may impede an orderly, predictable development. An additional undertaking is the forecasting of promise of marked improvement in the technology of UHPS as presently conceived.

3

3.2 Procedure

This evaluation elicits a series of quetions of impacting factors which are herein cited:

a. What geologic conditions are suitable for UHPS construction?

b. What amount of rock support may be required even for favorable geologic conditions?

c. What will UHPS cost and what is the construction period?

d. What is the relationship of the specific cost ($/kW) and the construction time under changing criteria for installed capacity, head, and storage capacity?

e. What type of equipment is, or will be, available for UHPS?

f. How do different types of equipment influence the physical characteristics, cost and operating capabilities?

g. What is the impact on the specific cost ($/kW) if, during construction, the estimated cost of the lower reservoir is significantly increased?

h. Are fluids other than water suitable for UHPS and are additional friction reducing additives to water feasible?

3.3 Geologic Consideration

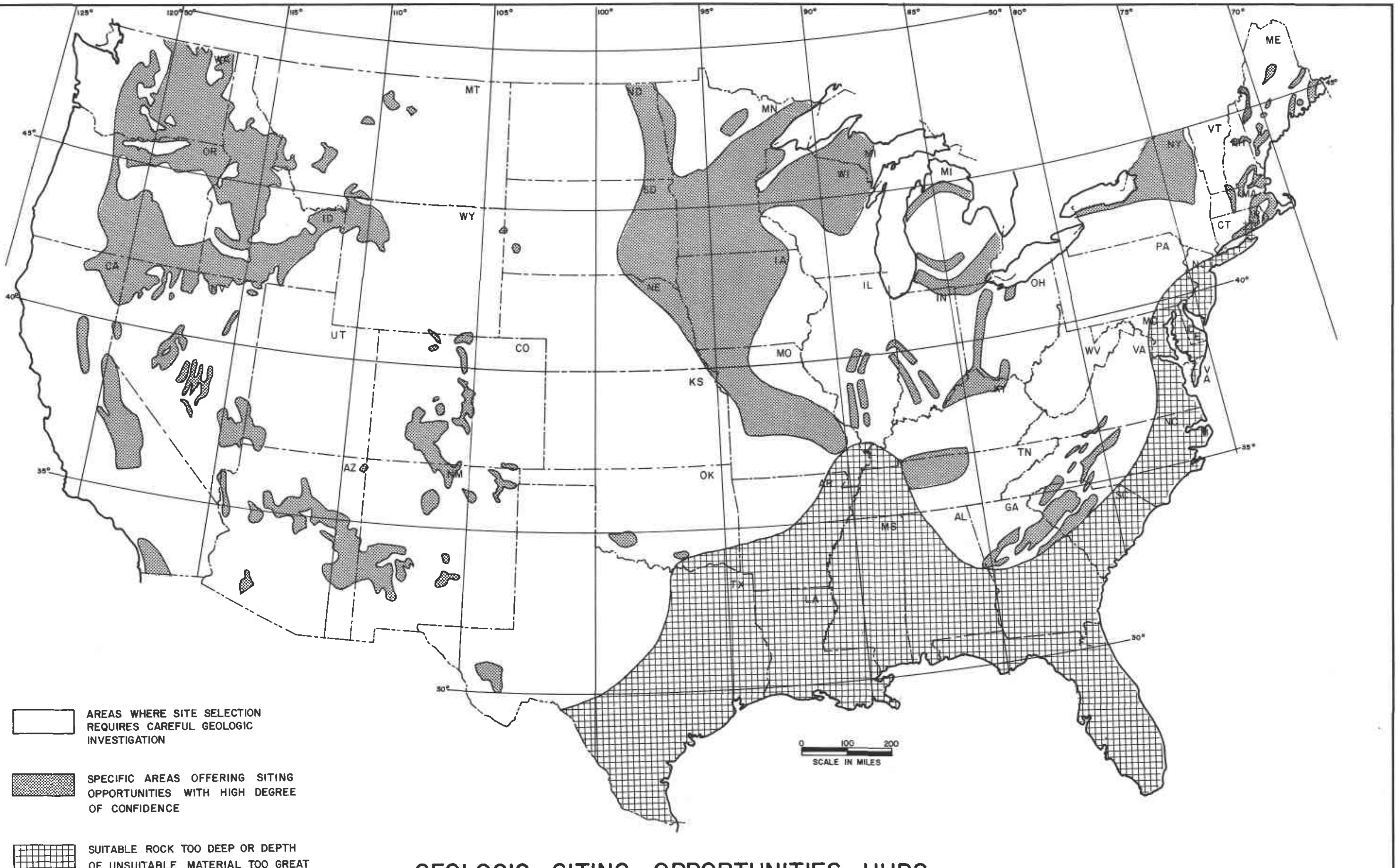
3.3.1 General

The geology of the United States, and, in fact, of all of the heavily electrified parts of the world, is sufficiently well known that those areas whose geologic characteristics are generally favorable for the development of Underground Hydroelectric Pumped Storage (UHPS) project locations can be delineated, e.g. Plate III-1. Proven boring techniques are available with which to obtain confirmation of geologic UHPS site suitability.

Numerous successfully constructed deep room and pillar mines in the United States exemplify the major techniques required to construct the shafts, adits, tunnels and underground caverns associated with UHPS.

3.3.2 Upper Reservoirs

A reservoir with storage capacity to store a water supply for 20,000 MWH at 1200 m (4000 ft.) head is typical of the UHPS projects judged most feasible in this report. The volume of such a reservoir is .008 km^3 (6400 acft), so that if its average depth is 10 m (33 ft) its area will be 79 ha (200 ac or 0.31 sq mi).



GEOLOGIC SITING OPPORTUNITIES - UHPS

(FROM ACRES AMERICAN STUDY 3 AND PUBLIC SERVICE ELECTRIC AND GAS STUDY 2, TABLE II-1)

MAIN PLATE III-1

There are no unusual topographic requirements for such a reservoir. The material required to be excavated from the mined lower reservoir will obviously be more than sufficient to form the structural enclosure for the upper reservoir, regardless of the site topography.

Assuming a four-year filling period (half the expected construction period), an average filling flow of 0.057 m^3/sec (2 cfs) is required. This is the normal average surface water runoff rate from a drainage area of 3.5 sq km (1.35 sq mi) in a typical temperate zone. The corresponding drainage area in a semi-arid zone would be several times greater. The capability of the region to provide storage capacity and make-up flow should be given early serious consideration.

Make-up flow necessary during project operation to replenish losses due to evaporation and seepage would be about one quarter the filling rate indicated above. Where water is plentiful and make-up is no problem there would be no incentive to go to unusual extremes to minimize seepage losses. Where the opposite is true, costly seepage prevention measures might be economically justified.

Given a zone of favorable geologic conditions for the shafts and deep underground caverns, there is little possibility that a satisfactory site for UHPS could not be found due to unsuitable upper reservoir geology. The technology for designing and constructing dammed and diked water impounding surface reservoirs in a wide variety of natural and man-made situations is well established.

Field investigations for the upper reservoir will be governed by the known geology of the area. Typically, they will include drill holes to obtain soil and rock samples, pressure tests with packers to indicate rock permeability, falling head permeability tests to indicate soil permeability, continuous seismic refraction surveys along the dike certerline for applying drill hole information for the determination of continuous profiles of soil zones, groundwater and bedrock profiles. Test trenches to rock will be required for observing joint patterns and joint fillings, and test pits in possible borrow areas to obtain soil samples for determination of the suitability of the available material for construction.

3

3.3.3 Shafts

As shown on PLATE IV-1, four vertical shafts, averaging about 1200 m (4000 ft) in depth, are required for a typical UHPS plant:

- a penstock shaft connecting the upper reservoir to the pump/turbines
- a lower reservoir vent shaft
- a shaft for primary surface access, including equipment transport, to the underground powerhouse
- a shaft from the surface for power cables and other lines and secondary access to the underground powerhouse.

With sound rock from the ground surface down, temporary and permanent support and dewatering through overburden would not be required. Where overburden is excessively thick, however, say over 45 m (150 ft), it would not preclude the feasibility of an otherwise advantageous UHPS site. At greater depths of overburden, with the likelihood of significant groundwater, the time and expense of sinking shafts might outweigh the advantages of sound rock at greater depth.

Given geologic conditions suitable for the shaft below the top 45 m (150 ft) and at the 1200 m (4000 ft) depth of the lower reservoir, only the presence of a major sandstone aquifer might rule out a UHPS site. Even in this case it might be determined that the expense of necessary grouting ahead of the shafts could be justified.

3.3.4 Underground Reservoir

Geologic conditions must be favorable for removing, by mining techniques, approximately 7.4 million m^3 (9.7 million cu yd) of rock at a depth of 1200 m (4000 ft) below the ground surface. With favorable conditions, rock removal for the powerhouse, associated caverns, and tailrace tunnels will not present any serious geologic problems. One of the UHPS schemes in Chapter 4 considered promising has a two-stage-in-series scheme involving a second powerhouse and small reservoir at intermediate depth. Because these require much less excavation than the lower reservoir, the cost implications of less than optimum geologic conditions are not as critical for them.

The rock in, above and below, which the extensive excavations will be made should be essentially impervious. Pervious water bearing sandstones such as the artesian Dakota formation of the Great Plains are not suitable for UHPS. Practically all other rocks are so dense as to be impervious for all practical purposes. The passage of water through such rock bodies as limestone, schist and basalt is through joints and other fractures. At UHPS depths, rock joints are normally tight and require no grouting. Where minor grouting is required chemical grouting should be used.

Sedimentary rocks that are flat bedded and well lithified, and structurally undeformed are most advantageous for UHPS. In this category are rocks such as limestone, dolomite, impervious sandstone and pre-Cretaceous indurated shales. Almost without exception, however, post-Cretaceous rocks, whether shales, sandstones, or limestones, are poorly indurated. Shales such as the Pierre which oxidize and expand when exposed to air must be avoided as should highly soluble evaporites such as gypsum and rock salt and moderately soluble anhydrite and sulfates.

Igneous rocks, although satisfactory, are generally not as advantageous as sedimentaries because their jointing is usually more intense and less regular in orientation. They are more likely to have weaknesses at depth because of hydrothermal alteration along faults. They are - where sound, unweathered and unfractured - usually stronger than sediments. Igneous rocks retain higher than usual in situ stresses under similar tectonic conditions. Basalts are also usually so jointed that they are among the most pervious of any rock bodies, although this is not always the case. The Serra Geral basalts in the Brazilian shield are intensely and minutely fractured, with joints and fractures relatively tight and little water passes through them. On the other hand, the Columbia River basalts in the Pacific Northwest are noted for their water-carrying capacity.

After excavation, the remaining rock should be able to stand alone or with only minimal support. Closely spaced joint sets should be avoided, as should rock badly fractured by tectonic activity. Rock which has been hydrothermally altered and/or significantly weathered is undesirable. Joints spaced closer than 300 mm (1 ft) should disqualify a site. Other joint characteristics, such as incipient joints, open joints, interrupted patterns, and continuous patterns, should be evaluated, as should the possibility of their being water bearing.

Rock should be excavatable by proven techniques of mining and underground cavern construction utilizing, where necessary, shotcrete, rock, bolts, steel mesh and gunite, and structural steel supports.

Field investigations for underground features should consist of a core boring program with a minimum of three holes - one hole on the centerline of the shafts, one in the powerhouse area, and one in the lower reservoir area. These holes will extend the full depth of the proposed structures in order to allow an accurate assessment of underground conditions and design parameters. Data assembled from this assessment should include:

a. Core inspection and description of the lithology, including apparent strength, porosity, permeability, partings

b. Percentage of core recovery and RQD*.

c. Compressive strength.

d. Penetration speeds, zones of lost water, artesian flow and voids encountered during drilling.

* RQD - Deere's Rock Quality Designation - percent of core made up of pieces 10 cm (4 in.) or greater. (Ref. 3)

e. Seismic and/or sonic measurements in bore holes to sense anomalies in longitudinal and vertical wave of propagation rate that might indicate zones of layered and/or abnormal stresses.

A summary of favorable and unfavorable geologic criteria for the upper reservoir, shafts and powerhouse cavern, and storage caverns is shown on Plate III-2.

3

3.3.5 Seismicity

The seismic character and earthquake possibilities of each preselected site must be evaluated individually. Underground openings such as tunnels, shafts, and large caverns are generally less susceptible to earthquake damage than surface structures. Despite this fact, underground features should not be located in or through active fault zones, or in potential seismically active zones.

3.3.6 Rock Mechanics

3.3.6.1 General

Deep underground mining technology, for years an evolving art, today represents a marriage of art and science. It is now generally accepted that computer aided stress analysis based upon a spectrum of hypothesized rock models derived from geologic interpretation and field and laboratory testing can add to the reliability of plans for dimensioning, shaping, and reinforcing underground mines and other openings.

For the prudent development of UHPS, it should be mandatory that unquestioned authorities in the field of rock mechanics actively participate in all decisions relating to rock behavior and support, beginning with site selection and continuing through design, construction, and post construction monitoring.

GEOLOGIC CONSIDERATIONS

UPPER RESERVOIR

Favorable

(a) Available source of water: surface streams; large, shallow ground-water aquifers
(b) Relatively impervious bottom conditions
(c) Good foundations for dam or dike
(d) Thin overburden (alluvium, colluvium, residuum, etc.)
(e) Availability of construction materials
(f) Low seismic risk zones

Unfavorable

(a) Pervious and/or soluble bottom
(b) Karst topography
(c) Permeable and/or compressible thick overburden
(d) High seismic risk zones

SHAFTS & POWERHOUSE CAVERNS

Favorable

(a) Thin overburden at shaft head
(b) Minimum disintegration of rock near surface
(c) Rock capable of standing alone or with minimum support after excavation
(d) Rock layers with minimum structural deformation
(e) Rock of low permeability
(f) Low seismic risk zones

Unfavorable

(a) Thick overburden or unconsolidated materials at shaft head
(b) Aquifers intersecting shaft
(c) Fissile or soluble rock
(d) Deformed, faulted, jointed rock (open discontinuities)
(e) Deep weathering in shaft rock
(f) High residual stresses in rock
(g) Erodable rock
(h) "Squeezing" ground (overburden or shales)
(i) Air slaking rocks
(j) High seismic risk zones

LOWER RESERVOIR

Favorable

(a) Thick bedded, massive, sedimentary rock
(b) Impervious and insoluble rock
(c) No significant aquifers
(d) Shale or other aquicludes above and below
(e) One bed of sufficient size, to contain cavern excavation
(f) Roof rock of "good quality" shale has different support requirement than "good quality" sandstone to allow maximum spans
(g) Structurally undisturbed rock (not folded)
(h) Low residual rock stress, ratios (horizontal to vertical)
(i) Low seismic risk zone
(j) Without closely spaced or open joints

Unfavorable

(a) Highly permeable rocks under artesian head
(b) Deformed rocks (folded
(c) Presence of faults, either active or dormant
(d) Fissile and/or soluble rock layers
(e) Closely spaced or open joints
(f) Rocks requiring costly support for moderate spans
(g) Hydrothermal alteration zones
(h) Excessive residual stresses
(i) High stress ratios (horizontal to vertical)
(j) Air slaking rocks
(k) High seismic risk zones

Major understanding of probable rock behavior should be sought from direct or reported observations and tests (should they be appropriate) in comparable existing underground workings with similar geology to the specific site being investigated. Diligence should be exercised to minimize time consuming and expensive but unpromising rock mechanics investigations. Bid plans for underground excavations and support being necessarily based largely on assumed conditions, will be subject to modification when rock has been excavated and its structure, properties and behavior directly observed. Application of experienced judgment to the final design of underground openings and permanent provisions for rock protection and support, based on the observed character and behavior of the excavated rock is vital to the success of an UHPS project.

3

A basic conclusion of this report is that the geologic considerations controlling the UHPS site screening process will preclude any critical rock support problems. Subsequent paragraphs outline the semi-empirical approach to the rock mechanics aspects of UHPS adopted as a basis for the conceptual designs of the underground facilities used in the feasibility studies.

3.3.6.2 Semi-Empirical Approach

The in situ vertical stress at any point is dictated by gravity and equal to the imposed load of overlying material extending to the ground surface. The magnitude of this stress as a function of depth is plotted in Plate III-3.

There is no predictable relation between horizontal in situ stress and the corresponding vertical stress. The only way to measure in situ horizontal stress in advance of deep UHPS excavations is indirectly by measuring cross-hole seismic velocity. Lateral velocities higher than vertical velocities imply lateral stresses correspondingly higher than vertical stresses.

The effects of in situ stresses, moreover on the behavior of mined and tunneled rock are not predictable with full confidence. Removing rock from the center of a stressed rock mass leads to a redistribution of whatever stresses in the rock mass so that higher than normal in-situ stresses alone are no cause for concern. The specific character of the rock - its joints, bedding planes, heterogeneities, anisotropy, stress-strain characteristics, the geometry of the rock cavities, the design of the rock support system, the rock excavation procedure, and the elapsed time between excavation and installation of the rock support, all influence the redistributed pattern of stresses in the rock mass, the loads on the rock supports, and any distortion of the rock cavities. When an underground cavity is created the stress resistance formerly offered by the excavated rock is transferred to the remaining rock peripheral to the opening, which becomes highly stressed.

Where a cavity is large relative to the spacing of the rock joints, the periphery of the cavity is normally strengthened by pinning with rock bolts, frequently augmented with wire mesh and/or shotcrete (sprayed on concrete mortar) and/or structural steel supports.

The stress equilibrium established after stress redistribution has taken place must be a stable one, with no threat of delayed stress readjustments that could jeopardize the integrity of completed structures and installed equipment.

Horizontal in situ stresses are the result of such factors as past tectonic stresses, general geology, and perhaps even specific rock birth conditions. At some sites where in situ stresses have been measured horizontal stresses were found to exceed corresponding vertical stresses by a factor of 2 or more.

For example, a relatively large number of measurements made in Scandinavian mines (Ref. 2) show that the sum of the horizontal principal in situ stresses exceeded by a great factor the corresponding in situ vertical stresses. Probable maximum horizontal in situ stresses based on this data are plotted as a function of depth on Plate III-3. This is not to say that even higher stresses might not be discovered at some potential UHPS sites.

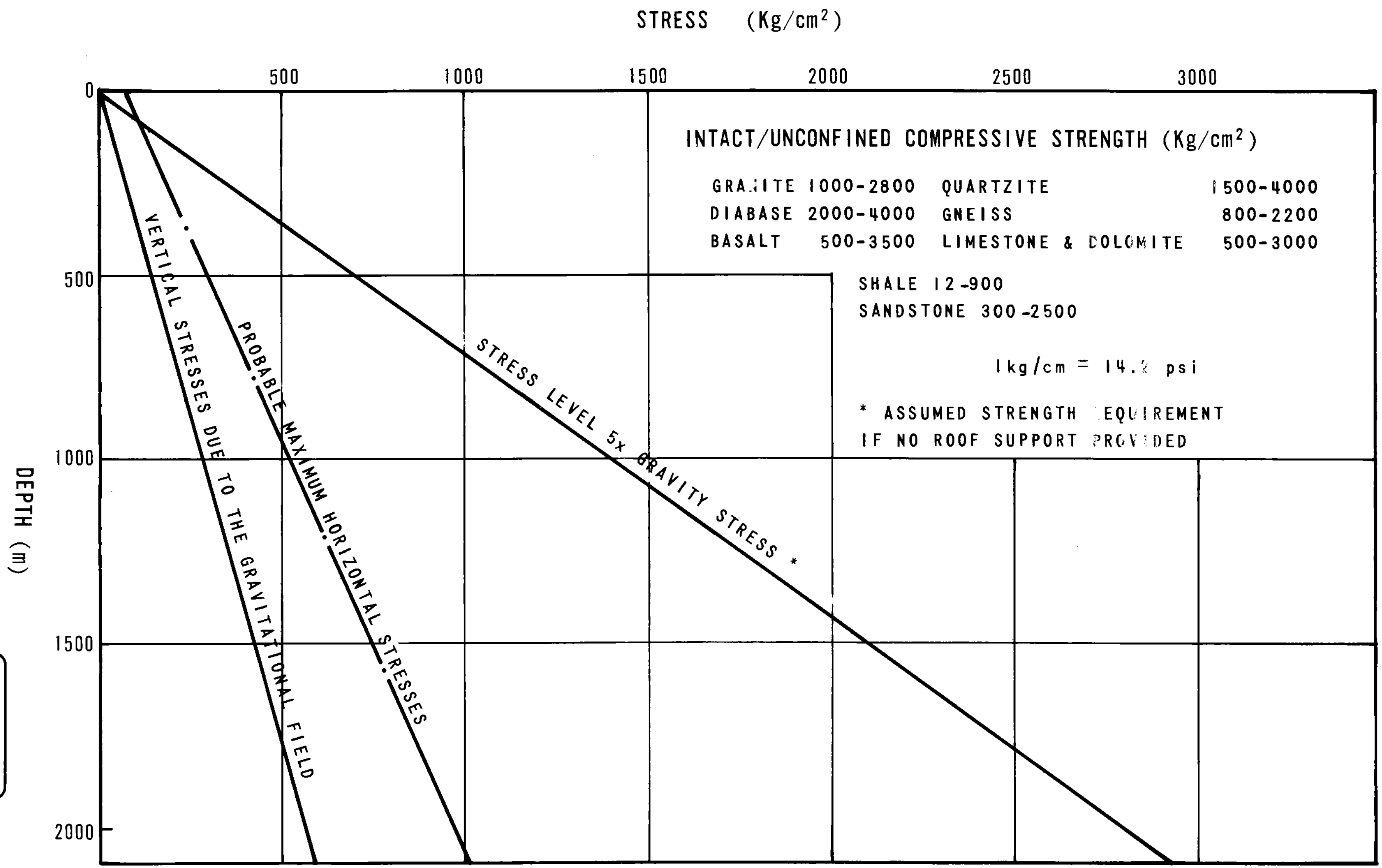
3

A room and pillar configuration formed by a grid of tunnels intersecting at right angles has been assumed for the lower reservoir. This shape is expected to be stable at selected sites and would minimize the excavation cost. As shown on Plate IV-1, the typical tunnel is 15 m wide by 25 m high (50 ft x 80 ft) with a crown of 7.5 m (25 ft) radius. The tunnels are spaced on 60 m (200 ft.) centers, leaving 45 m by 45 m (150 ft by 150 ft) pillars. The overall area covered by such a reservoir with capacity to store 20,000 Mwh at 1200 m (4000 ft) head would be about 800 m by 800 m (0.5 mi by 0.5 mi).

The large area of the reservoir relative to its depth will result in substantial stressing of the 170 pillars with the innermost pillars being stressed most highly. The assumption is made that pre-construction in situ vertical rock stress at lower reservoir level will be concentrated on the pillars after the reservoir is excavated. The concentration factor due to simple area reduction will be 1.8, so that a natural in situ stress of 375 Kg/CM^2 (5300 psi) will lead to a stress of 675 Kg/CM^2 (9600 psi) in the pillars. Under this stress the pillars will undergo an elastic compression of approximately 4 cm (2 in.) which will be reflected in ultimate settlement of the ground surface above the central portion of the mined reservoir by an equal amount.

Horizontal post-construction stresses are not as serious problem as vertical stresses. Although, as discussed earlier, horizontal in situ stresses exceed corresponding vertical stresses at some locations, the removal of rock adjacent to laterally stressed rock is of relatively minor consequence, leading to only a minor elastic yielding towards the excavation and stability. This is a quite different situation from that represented by the vertical load of the rock overlying the large lower reservoir which is substantial and requires the permanent support of the pillars. There is a possibility that at particular sites meeting the basic geologic criteria for UHPS, horizontal in situ stresses will result in popping rock (the sudden lateral ejection of rock fragments from the excavation walls) after excavation. Under such conditions, whose costs are covered by the contingency item in the estimates of this report, danger to workers would be minimized by the quick installation of rock bolts and/or shotcrete and wire mesh. With tunnel excavation sequenced from the periphery inwards any popping is expected to progressively diminish and then cease well before the reservoir excavation is completed. However, since the popping phenomenon is not well understood, confirmation for this expectation must await actual construction.

Where the intact unconfined compressive strength of the rock at a selected UHPS site is less than five times the in situ stress it is prudent to assume that roof support in the form of rock bolts will be required (see Plate III-3). On the same plate measured intact unconfined compressive strength values of various classes of rocks which might occur at selected UHPS sites are listed. Geologic siting criteria would normally preclude rocks in the lower strength range. In view of the broad range of test values the estimated UHPS costs reported herein cover a normal roof support system for the entire lower



ROCK STRESS LEVELS, STRENGTH REQUIREMENTS AND STRENGTHS

MAIN

PLATE III-3

reservoir. Even minor rock falls that represent no threat to the structural integrity of the lower reservoir should be prevented in the interest of safety of construction workers.

The assumed support system comprises 5 m (16 ft) grouted rock bolts at 1.8 m (6 ft) centers for the entire arch area supplemented with wire mesh and shotcrete for 30 percent of the arch area. The standard contingency allowance in the feasibility studies representing 25 percent of the estimated cost of all underground general construction, as discussed earlier in connection with popping rock, is intended to cover any additional rock support dictated by specific occurrences of chemically or mechanically weakened rock.

3.3.7 Area Acceptability for UHPS

Areas of the United States where the geologic conditions are especially favorable for UHPS are shown on Plate III-1.

While poor geology would preclude the development of UHPS in parts of virtually every state, only in Florida and Louisiana where overburden is excessively deep does there appear to be a total absence of suitable sites.

Specific sites should be selected and rated following an expert evaluation of available geologic mapping - published and unpublished - supported by a confirmatory drilling program as outlined above. The geologic considerations governing the selection and rating are as discussed earlier and summarized on Plate III-2.

3.4 Lower Reservoir - Configuration and Stability

Configuration of the lower reservoir is not necessarily optimum for minimum cost and minimal operating cost. However, as in any engineering design it is significant. Compactness will enhance the referenced question. In the case of this study the lower reserve pattern adopted is one with a slope towards the intake shaft for draining and the vent shaft placed at the highest reservoir point.

3

The stability of caverns can be affected by underground geology due to in situ stresses especially during operation as well as the structure itself. Inadequate quality can result in continued and progressive spalling, even to the point of failure, both of which are patently disruptive. Similarly if shafts and caverns are not watertight outflows would result in the change of the surrounding water table, areal extension depending on the degree of travel in the rock.

3.5 Storage Capacity Requirements

The load and generation characteristics of typical power systems in the United States can be analyzed to determine the economical potential for energy storage. Since UHPS developments proposed today would probably not go on line before 1988, such analysis is pertinent to the 1988-2000 period.

The six synthetic utility scenarios developed by EPRI for their use in assessing the value of R&D programs and projects (Table II-2, No. 9), being broadly representative of the electric systems of the United States expected for the mid-1980's are appropriate for this analysis.

TABLE III-1

GENERAL CHARACTERISTICS OF SCENARIO SYSTEMS - 1984

	MW				GENERATION % - 1984, (1978-84)							
						Steam			Comb.	Hydro		Comb.
System	Generation	Load	Network-kV	Peak	Nuc.	Coal	Oil	Gas	Turb.	Conv.	PS	Cycle
A	53,500	44,000	Mid-range 345,230,138	Summer	21 (40)	60 (35)	7 (6)	- -	9 (19)	1 -	2 -	- -
B	46,000	38,000	Dispersed 500,230	Winter Summer-high	10 (43)	20 (35)	24 -	- -	6 (9)	38 (4)	2 (2)	- (7)
C	22,000	16,500	Highly-dispersed 345,230,138	Summer	20 (31)	50 (56)	15 -	- -	5 (13)	7 -	3 -	- -
D	32,000	26,000	Concentrated 500,230	Summer	25 (68)	35 (8)	25 (9)	- -	15 (15)	- -	- -	- -
E	45,500	37,000	Mid-range 345,138	Summer	15 (25)	25 (63)	5 -	50 (12)	5 -	- -	- -	- -
F	32,000	26,000	Mid-range 500,230,138	Summer Winter-high	31 (64)	9 (19)	45 (6)	- -	5 (5)	5 -	5 (6)	- -

Source: EPRI

The synthetic systems which are most applicable in the various regions of the United States are shown on Plate II-1.

General characteristics of these systems are tablulated on Table III-1.

Reference 9 Table II-2 includes for each scenario system:

3

- Separate plates and data tabulation of weekly (7 day) load cycle and load duration for spring/ fall, summer and winter

- Generation plant description, generation characteristics and generation installation dates

- Monthly peak

For simplicity in the present analyses loads indicated by EPRI as occurring in 1984 are assumed to be 1988 loads and load growths are assumed at 6% per year with no change in load shape.

UHPS storage capacity requirements are established by simulating system operation over a representative period of years for a given amount of UHPS energy storage. The amount of storage capacity required is defined as the amount at which the marginal economic benefit of additional storage is negative. (See Paragraphs 8.9 and 8.10).

3.6 Pump/Turbine Units

3.6.1 General

Two types of equipment can be counted on to operate reliably under heads of approximately 1200 m (4000 ft): recently developed, unregulated, multi-stage, reversible pump/turbines; and regulated, tandem units, such as those which have been used in European high head pumped storage plants for many years, with a Pelton turbine on a common shaft with a multi-stage pump and a generator/motor.

The maximum design head of the single stage, reversible, wicket gate controlled pump/turbine prevalent today at conventional pumped storage hydroelectric plants has been steadily increasing over the years. Two major manufacturers report the practical limits on the design head for these units as 750 m (2500 ft) Escher Wyss) and 800 m (2600 ft) (Toshiba). Utilization of conventional single-stage, reversible units for UHPS at 1200 m head would thus require two of them in series.

It is noteworthy that European practice for conventional hydroelectric pumped storage (CHPS) plants with heads exceeding the upper limit for regulated single-stage pump/turbines is to utilize either unregulated, multi-stage, reversible units or regulated, tandem units rather than two single-stage pump/turbines in series.

One manufacturer - Escher Wyss - has completed essential model tests and performed mechanical design investigations for two-stage, regulated pump/turbines. While none of these units is in operation or on order today, it is reasonable to assume that the advent of UHPS would stimulate their development (Reference III-8).

3.6.2 Unregulated, Multi-stage, Reversible Pump/Turbines (Reference III-6)

Two extra-high-head, unregulated, multi-stage, reversible pump/turbine installations are in operation today and another is under construction, as tabulated below:

Plant	Location	Head m	Head ft	Unit Gen. Cap. MW	No. of Units	Pump Stages	Mfr.	Status
Chiotas	Italy	1070	3500	150	8	4	Hydroart, Escher-Wyss	Op
Edolo	Italy	1290	4200	142	6	4	Hydroart	Const.
LaCoche	France	930	3000	79	7	5	Vevy, Neyrpic	Op

In all these plants for reasons of reliability, simplicity and economy, pumps are started-up in the watered condition. At the Italian stations, pumps are connected back-to-back electrically to an appropriate generating unit, generating; and at LaCoche, asynchronously by direct insertion on the network at reduced field voltage.

Although start-up in the unwatered condition would require less power and be more economical, technological considerations prevent this for the following reasons. (Reference III-6).

- Machines might fill up asymmetrically, causing intolerable transverse vibration of rotating parts because of great distance between machine shaft bearings.

- The system of devices necessary to evacuate air from the intricate multi-stage volute would be very complex and of doubtful reliability in commercial application.

- Similarly complex, and of doubtful reliability, would be the system to evacuate lubricating water from the interstage seals. Lubrication is necessary to avoid the hazard of stalling as a result of thermal expansion, unavoidable misalignment of the rotating part with respect to the stator, or transverse vibration of the rotating parts. Lubricating water has to be evacuated to prevent the formation of water rings that might increase the resisting torque uncontrollably. The evacuation cannot be done by gravity for the stages after the first because of the centrifugal effect of the immediately underlying stages.

Electrically tandem, back-to-back, fully watered, pump starting will probably be necessary with these units, for the reasons discussed above. So that all the pumps can be started it will be necessary to provide at least one tandem unit at each station otherwise equipped with multi-stage reversible units.

The Pelton wheel on the tandem unit could serve as a back-to-back partner for any of the neighboring multi-stage reversible pumps.

The requirement that these uncontrolled units be loaded in steps equal to their capacities should be of minor economic consequence in the large electric grid systems to which they will connect. It should be noted that since it is hydraulically impossible to control centrifugal pumps, hydroelectric pumped storage plants are characteristically step loaded when in the pumping mode.

Estimates for the present study are based on 333 Mw units at 514 rpm and 1200 m (4000 ft) head. Such units would be about one third larger in diameter and correspondingly higher than the Chiotas units but their critical stresses would only be about 10% higher. Other characteristics of these units are:

Turbine efficiency	89.5%	
Turbine unit flow	32.9 m^3/sec	(1160 cfs)
Pump efficiency	89.5%	
Pump unit flow	27.5 m^3/sec	(970 cfs)

3.6.3 Regulated Tandem Units (See Reference No. 9)

Among the extremely high head stations utilizing tandem units are the following:

Plant	Location	Head m	Head ft	Unit MW	No. Units	Shaft
San Fiorino	Italy	1440	4700	140	2	Vert.
Roncovalgrande	Italy	754	2500	127	8	Vert.
Motec	Swit.	685	2200	24	2	Hor.
Lunersee	Austria	977	3200	46	5	Vert.
Rottau	Austria	1100	3600	200	2	Vert.

The multi-stage pump component of these units corresponds basically to the reversible multi-stage pump/turbines discussed earlier.

The Pelton turbine component is virtually identical to a standard Pelton turbine. Data on the largest Pelton turbines in the world, all of them vertical shaft machines, from an output and size standpoint, are as follows:

Plant	Location	m	ft	Unit Gen. Cap. MW	Runner Diameter m	Runner Diameter in.	No. of Nozzles	Mfr
Aurland	Norway	840	2755	240	4.26	168	6	Kvaerner Brug
New Colgate	California	410	1350	167	5.44	214	6	Voith
Rottau	Australia	1100	3600	200	2.66	105	6	Voith

Estimates for the present study are based on horizontal shaft double runner, four nozzle 333 MW units generating at 360 rpm and 1200 m (4000 ft) head. The turbines would be smaller in diameter than the first two of the above, while the pumps with five stages would be about 18% greater in diameter than the proposed reversible multi-stage units.

Other characteristics of these units are:

Turbine efficiency	91.5%
Turbine unit flow	32.2 m^3/sec (1140 cfs)
Pump efficiency	89.5%
Pump unit flow	27.2 m^3/sec (960 cfs)

3.6.4 Regulated, Single-Stage, Reversible Pump/Turbines

W. Meier's authoritative analysis of the potential for further development of these machines (References III-7) includes the following significant points:

- Today's highest head units - 620 m (2000 ft) have a top efficiency of about 2% less than that which is attainable at half that head.

- At 1000 m (3300 ft) head, an additional 6% fall off in efficiency would be likely; to reduce this fall off would require careful mechanical and hydraulic redesign of a runner to operate at a specific speed about 50% higher than today's limit; stay vanes and wicket gates would have to be so thick for stress reasons that added hydraulic losses would significantly offset efficiency gained by increasing the specific speed.

A scheme similar to one proposed by Harza (PLATE II-1) Study 4), involving two power plants in series equipped with identical 600 m (2000 ft) head turbine/pumps, one plant at 1200 m depth, the other at 600 m, with a small intermediate reservoir, is analyzed here.

The characteristics of the units considered are:

Turbine capacity	250 MW	
Turbine efficiency	91%	
Turbine flow	47.1 m^3/sec.	(1,670 cfs)
Pump efficiency	91%	
Pump flow	41.5 m^3/sec	(1,460 cfs)

3

3.6.5 Regulated, Two-Stage, Reversible Pump/Turbines

Although none of the specific schemes considered here includes these units, which are still in the planning stage, they should not be overlooked when the time comes to design a specific UHPS plant.

3.6.6 New Pump/Turbine Units

The turbomachinery used for this study purpose has been existing types or extensions thereof. This does not preclude advanced machinery.

The scaling of multi-stage reversible pump/turbines from existing sizes to larger sizes used herein seemingly results in no problems to manufacturers. This information was obtained from Escher Wyss, Switzerland and Hydroart, Italy.

Argonne National Laboratories, in cooperation with Allis Chalmers has a program for the Division of Energy Storage Systems, Department of Energy in which is included preliminary sizing, design, and cost estimates for 500 MW, multistage, gateless, RPT systems for 1000, 1250, 1500, and 2000m net heads. Results of this undertaking should add to the science of UHPS. A similar study for two-stage RPT is also being done.

It is further understood that ANL is prepared to investigate the impact on the motor/generator when the regional electric grid is taken into consideration as contrasted to consideration of the UHPS alone.

3.7 Electrical Equipment

The electrical equipment and its arrangement necessary for UHPS are within the range of existing experience. No new technology is required. Estimates herein are based on equipment configurations typical of existing conventional hydroelectric pumped storage plants.

Each generator/motor unit is connected to a companion 3-phase transformer. The transformers are conventional oil-filled units, forced-water called, installed in enclosures and protected by CO_2 fire protection systems. The transformers are paralleled on the high voltage side in pairs, with gas insulated bus eliminating any open, non-insulated high voltage connections. Unit switching is accomplished with generator/motor circuit breakers at machine voltage. Phase reversing switches between the units and the breakers are mounted vertically on the upstream side of the generator/motor enclosure at the operating floor level.

Pump starting equipment will vary depending on the nature of the pump/turbines. Single-stage reversible units would be synchronously started as pumps in the unwatered condition, utilizing a static converter/inverter system. Multi-stage reversible units would have provision for back-to-back pump start-up in the watered condition. The pump components of tandem units would be started mechanically by their companion Pelton turbines.

3

3.8 Evaluation of Civil Works Cost

The main effort was directed to estimating the cost of the civil underground works, mainly, the vertical shafts and the lower reservoir.

It was assumed that all labor would be provided by Construction Labor Unions. Accordingly, the labor productivity was estimated, where possible, from labor contracts available from previous jobs, the labor rates, as of January, 1977, being taken from Engineering News Record (ENR).

Considerable investigation of published studies regarding methods for sinking shafts to great depths was made. Of particular help was Ref. III-5, a study by the Dravo Corporation for the Bureau of Mines, entitled "Analysis of Large Scale Non-Coal Underground Mining Methods", January, 1977.

In view of the importance of the time element in the construction of these UHPS projects, it was decided to assume that the three important vertical shafts: the main access shaft, the high voltage bus shaft and the penstock shaft, be sunk simultaneously working 3 shifts per day, 6 days per week. Two shafts are used for mucking the underground excavation and the third would serve as a personnel and service shaft. Each mucking shaft is provided with a double drum production hoist using two 22 ton skip hoists.

Assumed available production time for sinking the shafts is 19.5 hours per day based on a 3 shift per day schedule. The shafts are sunk full face by the conventional method of drill, blast and muck with access from the surface. The concrete lining would follow not far behind excavation.

Drilling rates of 20 inches per minute were used resulting in sinking rates of 1.8 to 2.6 m (6 to 8.5 ft)/day depending on the shaft size with the lower rate for the larger size shaft. (Including drilling, blasting, mucking and concreting.)

The resulting direct cost for excavation only varies between \$80 - \$120/m^3 (\$61 - \$92/c.y.) for large size shafts to about \$250/m^3 (\$191/c.y.) for small size shafts .

With respect to the lower reservoir cost, it is noted that due to the large number of working faces, excavation should be highly productive in terms of labor and equipment. It was therefore assumed to use a 3 shift per day, 6 days per week work schedule.

Separate labor, material and equipment components have been computed for the two types of operation used for the excavation of the lower reservoir: heading and benching. It was determined that about 25 percent of the total lower reservoir volume will be excavated by the heading method and the remainder, 75 percent, by the benching method.

Productivity is assumed at about 7000 m^3 (9100 c.y.)/day corresponding to the skip hoists capacity of 3500 m^3 (4600 c.y.)/ day for each shaft (including downtime.)

For the lower reservoir excavations the available production time was reduced from 19.25 hours/day to 15.4 hours/day to take into account distances to the portals, idle time, etc.

The ratio between the direct cost of excavation by the heading method and by the benching method is about 1.8. This is due mainly to the fact that a benching operation requires only one hole per 25 sq. ft. area and 0.8 #/cy. of explosive versus one hole per 7 sq. ft. and 2 #/cy. of explosive for the heading method.

3

After allowing for ventilation, air, water, power, compressor station operation, hoist operations and repair, and the crushing of about 20 percent of the entire excavated volume, the average direct cost of the lower reservoir excavation amounted to $\$18.15/m^3$ (\$13.89/c.y.).

The amount of money provided for rock support consisting of grouted rock bolts, wire mesh and shotcrete, divided by the lower reservoir volume corresponds to an additional $\$3.85/m^3$ (\$2.95/c.y.). In addition to this, $\$2.17/m^3$ (\$1.66/c.y.) has been provided for rock disposal for the entire quantity of rock excavated from the lower reservoir minus the volume of rock needed to build the upper reservoir rock fill dikes; \$0.54 is added for differential costs associated with overtime work.

The cost of all other civil work structures, such as powerhouses, upper reservoirs, intakes, etc., has been estimated based on information from recently built or designed projects.

The majority of auxiliary equipment being similar to that required for any underground power plant, its cost has been estimated to a large extent based on reliable available information.

3.9 Contingencies

In view of the unusually large amount of underground civil works required by this type of project it was considered necessary to analyze more closely how much money should be allocated for contingencies.

Different contingency coefficients were adopted for the "above ground" civil works and the "underground" civil works. The "above ground" civil works consist mainly of the construction of the upper reservoir which was designed assuming a man-made reservoir covered with an impervious membrane, one of the most conservative type of designs. Consequently, for the "above ground" civil works a contingency coefficient of 15 percent was considered adequate.

The evaluation of what may be considered an adequate contingency coefficient for the "underground" civil works is significantly more difficult due to the many aspects involved.

Unexpected adverse geologic conditions are not anticipated since the area occupied by a UHPS project is limited and the nature of the field investigation program which would be completed before the starting of construction eliminates such possibilities. In other words, any site which may have significant faults or inadequate rock conditions at the lower reservoir level will be eliminated during the site selection program. What may be expected, as physical contingencies, are minor local faults, popping rock, areas of badly jointed rock, etc. These conditions may necessitate more rock support than provided in the quantity estimates. Any additional need for support will also reduce the rate of advancement and increase the labor and equipment cost.

In view of the above, it was decided to apply to all items included under "underground" civil works a contingency coefficient of 25 percent.

It should be mentioned that included in the cost estimate for civil works is not only excavation but also a significant amount of civil works, especially inside the power house, which are not too sensitive to changes in the rock conditions.

For the electro-mechanical equipment the contingency coefficient was estimated at 10 percent.

3

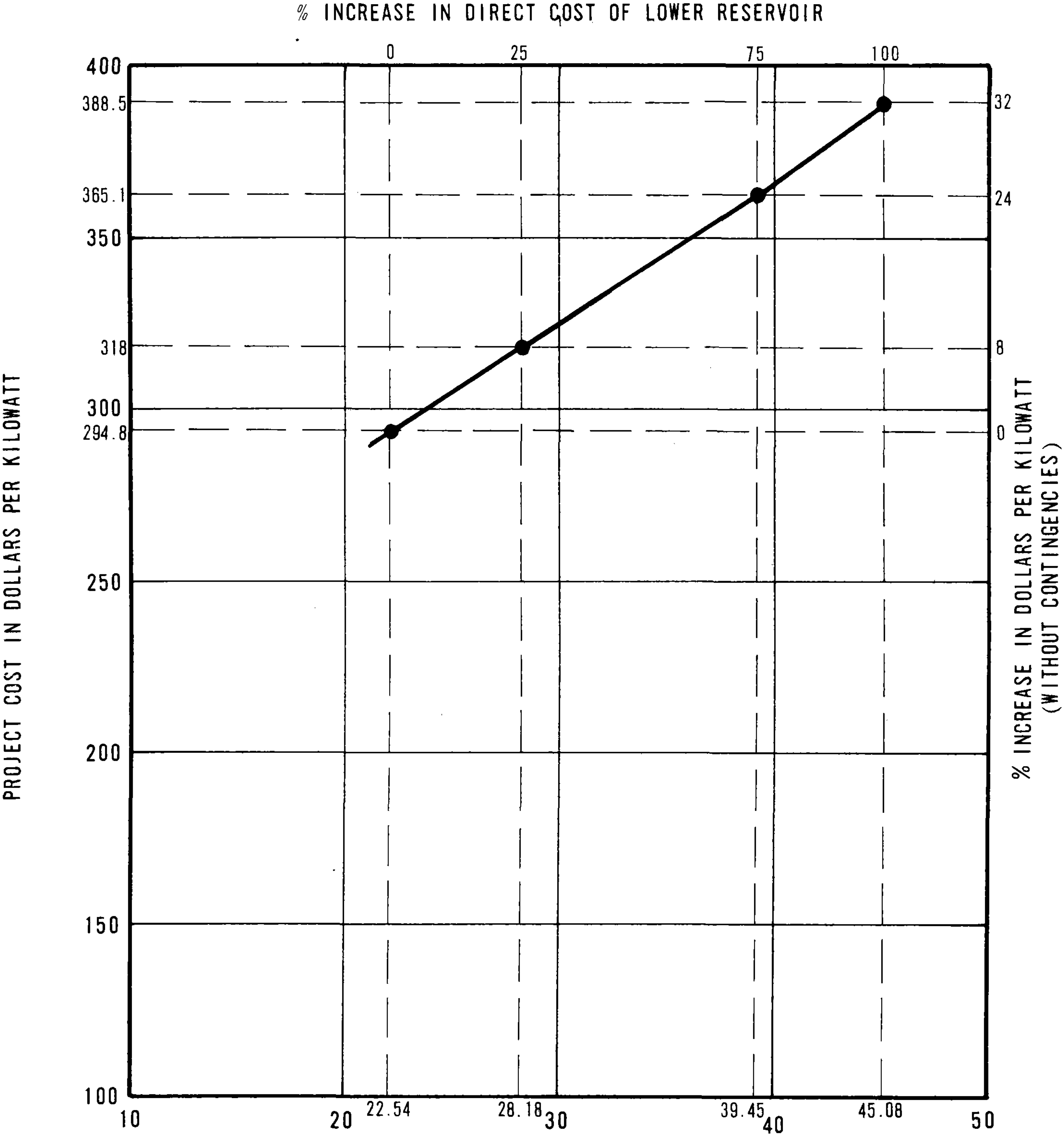
The engineering, supervision and overhead cost has been estimated at 12 percent of the total project cost including contingencies. This approach was used assuming that should contingencies develop, the construction project cost would increase; and consequently more engineering and supervision work would be needed to solve the unexpected problems.

3.10 Lower Reservoir Excavation Cost Sensitivity

The man-made lower reservoir is the main difference between a conventional PS and an UHPS project. The magnitude of the volume of underground excavation required and the cost associated with it are apparently the main reasons why until now no project of this type has been built.

In view of this situation, it was considered appropriate to perform a sensitivity analysis regarding the cost of the lower reservoir. Starting from the estimated direct cost of excavation of $24.71/m^3$ which includes an allowance for supports, disposal and overtime, studies were made to determine if a significantly reduced price would result from using the latest methods in rock excavation such as advanced type of boring machines, water jetting, etc. After obtaining disappointing results, and to ascertain that no new technologies were missed, the opinion of Dr. Ronald G. Hirshfeld, consultant and former

CAPACITY 2000 MW
HEAD 1200 M
STORAGE: 10 HRS



DIRECT COST OF LOWER RESERVOIR EXCAVATION ($/m³)
(Including Rock Bolts and Shotcrete)
WITHOUT CONTINGENCIES FOR LOWER RESERVOIR EXCAVATION COSTS

INVESTMENT COST ESTIMATES OF ONE DROP SCHEME
(EFFECT OF LOWER RESERVOIR EXCAVATION COST OVERRUN)

MAIN

NOTE: - COSTS AS OF JANUARY, 1977 PRICE LEVEL; NO AFDC, INFLATION OR ESCALATION

PLATE III-4

MIT professor, who was involved in several studies made for U. S. government agencies regarding new methods for rock excavation was solicited. His opinion was that no significant "revolutionary" changes may be expected in this field during the next ten years. (See Appendix IV.)

A sensitivity analysis was made to assess changes in project cost due to increased underground excavation. rock bolting and shotcrete (Plate III-4).

3

For the first analysis, which considered a direct cost increase of 25%, the amount reserved for underground contingencies, showed that an increase in direct costs from $\$22.54/m^3$ to $\$28.18/m^3$ yielded an increase in project cost of 8% or from \$294.80 to \$318.00/kw. This latter figure is the estimated cost for the project using the estimated direct cost and contingencies.

A second analysis considered that the direct cost increased by 75%, from \$22.54 to $\$39.45/m^3$. The results showed an increase in project cost of 24%, or from \$294.80 to \$365.1/kw.

The third analysis increased the direct cost from \$22.54 to $\$45.08/m^3$, a 100% increase. The resultant increase in project cost was from \$294.80 to \$388.50/kw or a 32% increase in project cost.

Increases of the excavation cost in the range of 100 percent are highly improbable due to the detailed field investigation which will precede any site selection and the construction go-ahead decision.

Smaller percentage cost increases of the excavation of the order of 50-60 percent apparently can be absorbed without jeopardizing the project feasibility.

3.11 Other Cost Variables

The cost of the above mentioned 2000 MW UHPS project increases about 11 percent (due to increased storage requirements) if the head is reduced to 900 m, and decreases about 2 percent if the head is increased to 1500 m.

The construction time up to commercial operation of the first unit is much longer for the 900 m (2950 ft) and 1500 m (4900 ft) head plants, and amounts to an additional 9 and 5 months, respectively.

The problems related to high in situ rock stresses should normally increase when the head is increased from 1200 m (4000 ft) to 1500 m (4900 ft).

In view of the above, it is concluded that the two UHPS schemes which would be optimized have a head of 1200 m (4000 ft).

For constant head (1200 m (4000 ft) and constant storage (10 hours), a decrease in capacity from 2000 MW to 1300 MW decreases the construction time (8 months), but increases the cost ($/KW) about 11 percent.

Conversely, an increase of capacity to 2700 MW increases the construction time (9 months), but reduces the cost about 5 percent.

However, when the above mentioned cost figures are computed, taking into consideration interest during construction and/or applying the present worth method of economic comparison, the minimum investment figures move close to the 2000 MW zone.

The effect of storage on the UHPS investment cost has also been investigated during the study as preparatory work for the next phase. The cost of an incremental hour of storage for a 2000 MW, 1200 m head plant is equivalent to about $14/kW.

In view of the very large amount of excavation, 7,400,000 m^3 (9,670,000 c.y.) required for building the lower reservoir and its significant part in the total project cost, it was considered necessary to perform a sensitivity analysis of the total project cost as a function of lower reservoir cost over-run.

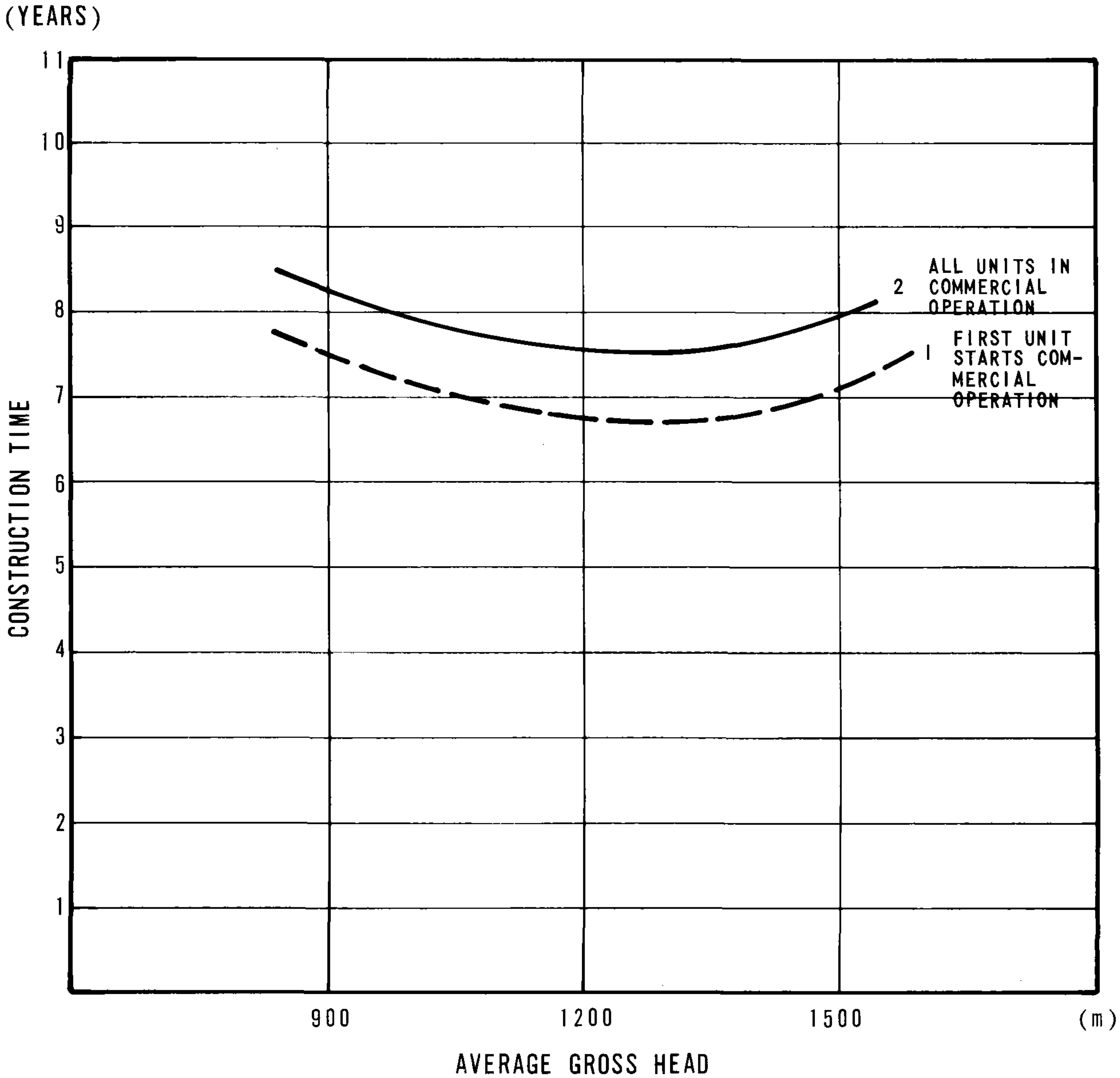
The results have shown that over-run of the lower reservoir estimated excavation cost of 50-60 percent would result in total project cost over-run of less than 10 percent.

Regarding the equipment, it was concluded that a 2000 MW, 1200 m head, UHPS plant can be equipped with either multi-stage reversible pump/turbine, tandem units or single stage reversible units cascade arrangement. The scheme with tandem units is 9-10 percent more expensive.

It is recommended that the simulated power system analyses for economic comparison use an UHPS scheme with multi-stage reversible pump/turbine and another with single stage reversible units (cascade arrangements).

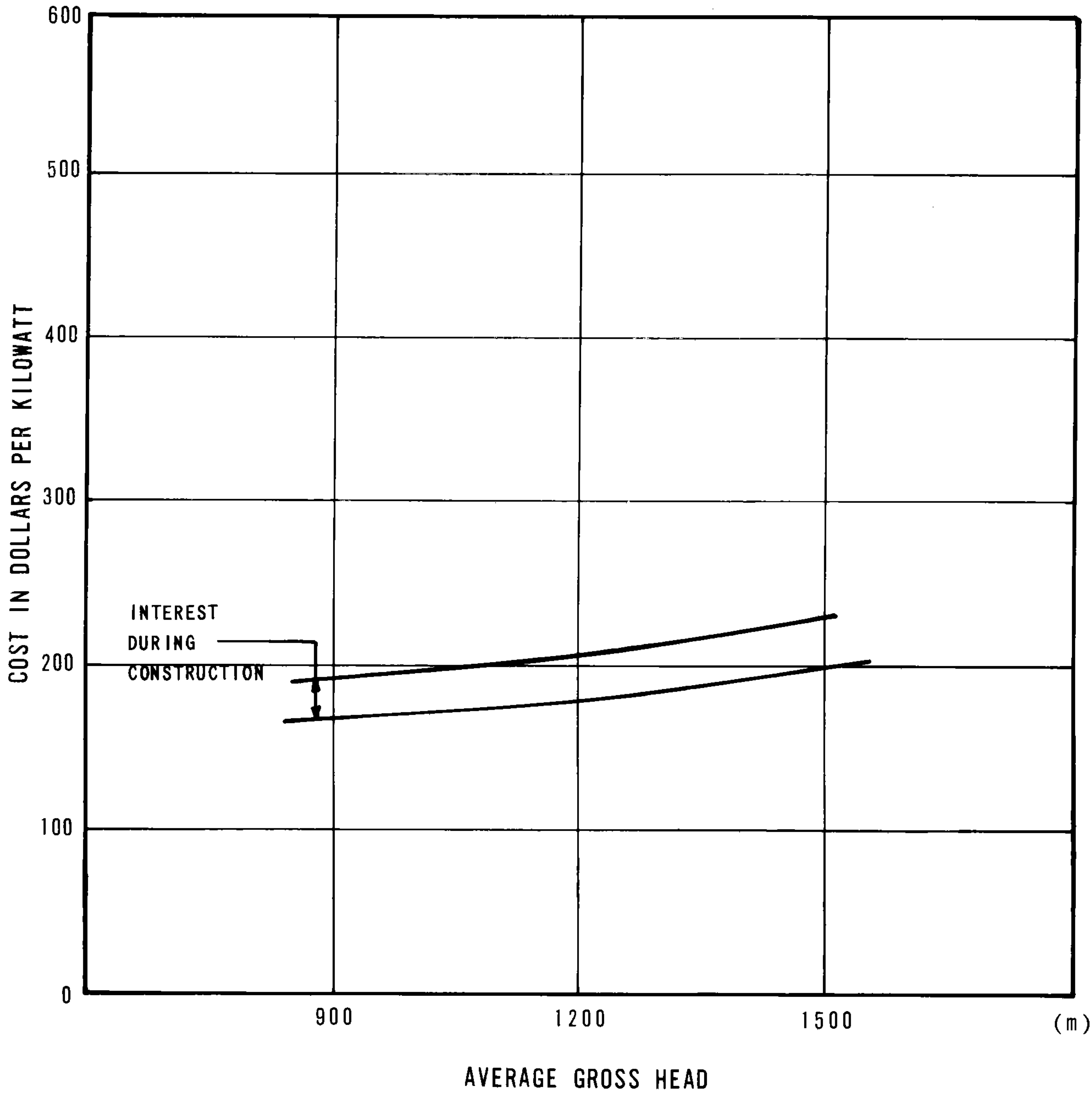
3.12 Effect of Head, Installed Capacity, and Storage on Construction Time and Investment Cost

In order to evaluate the effect of head, capacity,



CONSTRUCTION TIME FOR ONE DROP SCHEME
(EFFECT OF HEAD)

NOTE:
- 10 HOURS STORAGE, 2000 MW CAPACITY
- LOWER RESERVOIR EXCAVATION AND SHAFTS SINKING A SIX (6) DAYS / WEEK OPERATION
- TIME COUNTED FROM THE AWARD OF THE CIVIL CONTRACT
- MULTISTAGE REVERSIBLE PUMP/TURBINES



COST ESTIMATES OF GENERATING CAPACITY
(EFFECT OF HEAD)

NOTES:
- SINGLE DROP
- COST OF STORAGE EXCLUDED
- MULTISTAGE REVERSIBLE PUMP/TURBINES
- COSTS AS OF JANUARY 1977
- 2000MW CAPACITY
- INTEREST ASSUMED 3.8% PER YEAR
- NO INFLATION OR ESCALATION INCLUDED

MAIN PLATE III-6

and storage on construction time and investment cost of UHPS projects, four UHPS schemes in addition to the three described in Chapter 4 have been studied:

Scheme IV - 2000 MW, head 1500 m, storage 10 hours
Scheme V - 2000 MW, head 900 m, storage 10 hours
Scheme VI - 2700 MW, head 1200 m, storage 10 hours
Scheme VII- 1300 MW, head 1200 m, storage 10 hours

The cost estimate summary for these four schemes are presented in Appendix I. The construction schedules with annual disbursements are presented in Appendix III.

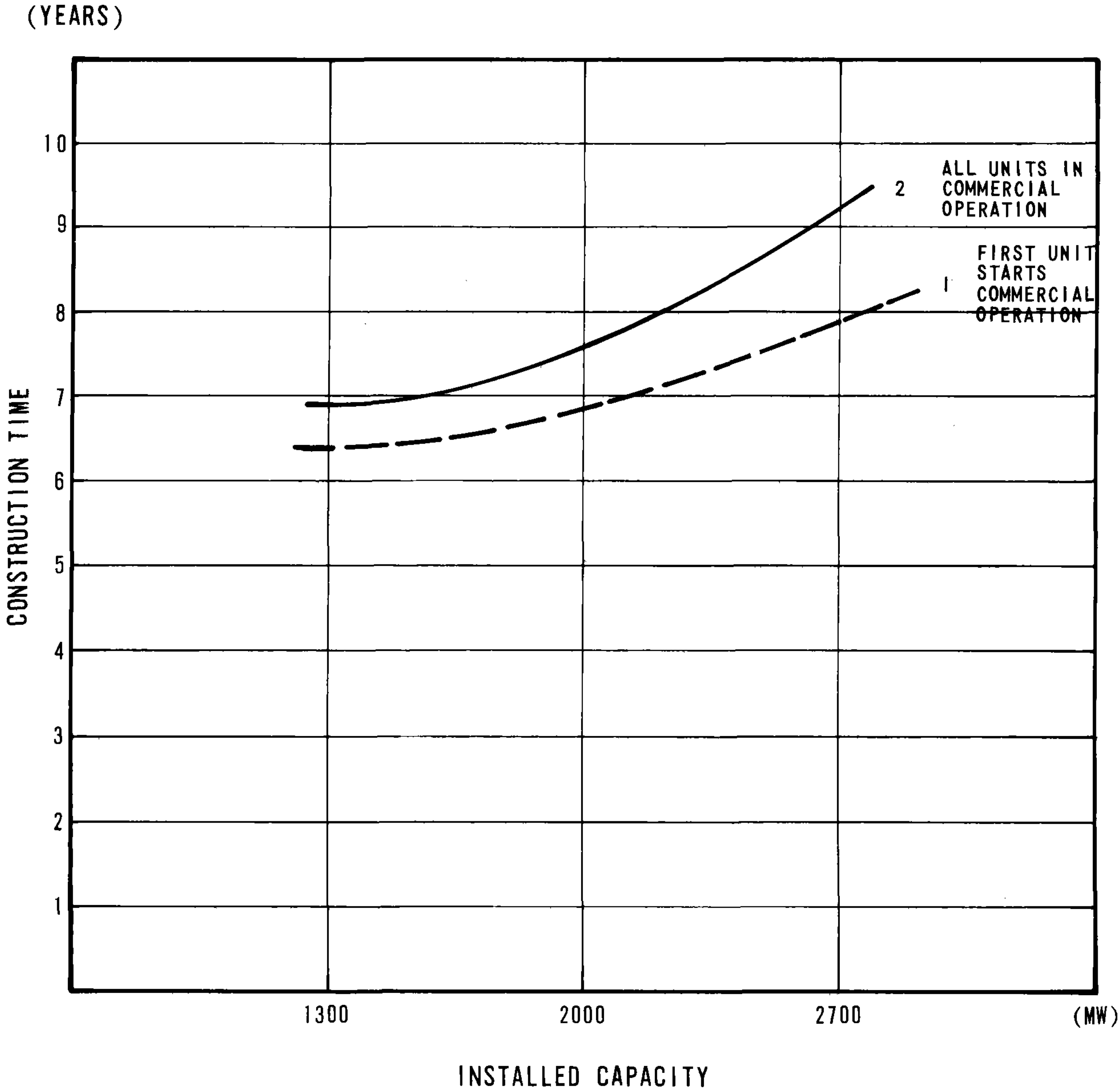
3.12.1 Effect of Head

Plate III-5 shows the effect of head on the construction time of 2000 MW, 10 hours storage, one drop, UHPS projects.

It can be seen that for the assumptions made in this study, the minimum construction time is about 6½ years for the first unit commercial operation; and 7½ years for total in commercial operation, for heads around 1250 - 1300 m. (4100-4260 ft.).

Plate III-6 shows the investment (present cost $/kW) as a function of head for a 2000 MW, 10 hours storage installation. As expected, the direct cost decreases with the head. However, the incremental cost decrease is less significant for heads exceeding about 1200 - 1300 meters (4000-4260 ft.).

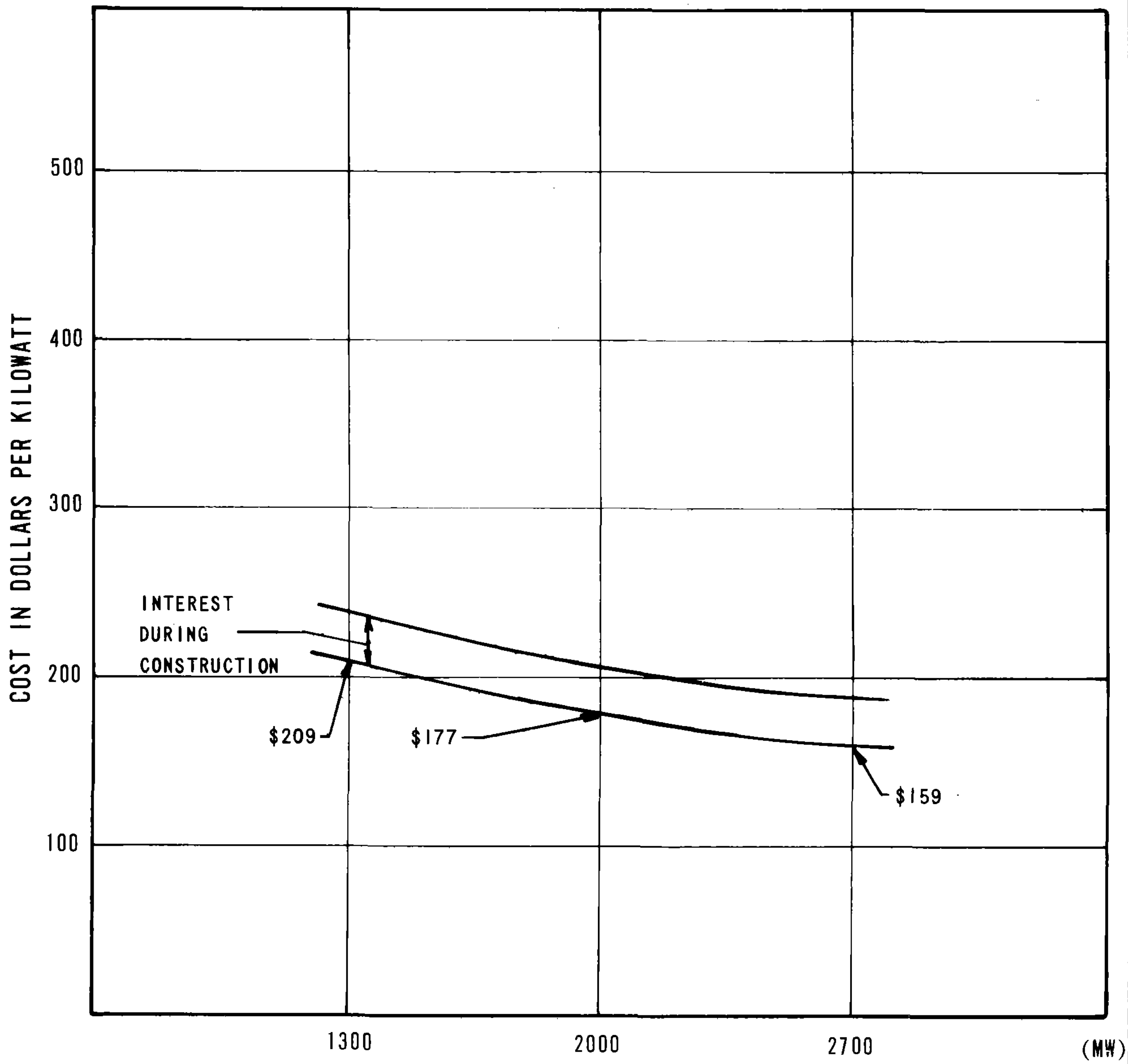
On the same figure is plotted the cost of the plant ($/kW) including the interest paid during construction (Curve 2). It can be seen that this curve has the same tendency to show a



CONSTRUCTION TIME FOR ONE DROP SCHEME
(EFFECT OF CAPACITY)

NOTE:
- 10 HOURS STORAGE, 1200m HEAD
- LOWER RESERVOIR EXCAVATION AND SHAFTS SINKING A SIX (6) DAYS / WEEK OPERATION
- TIME COUNTED FROM THE AWARD OF THE CIVIL CONTRACT
- MULTISTAGE REVERSIBLE PUMP/TURBINES

MAIN PLATE III-7

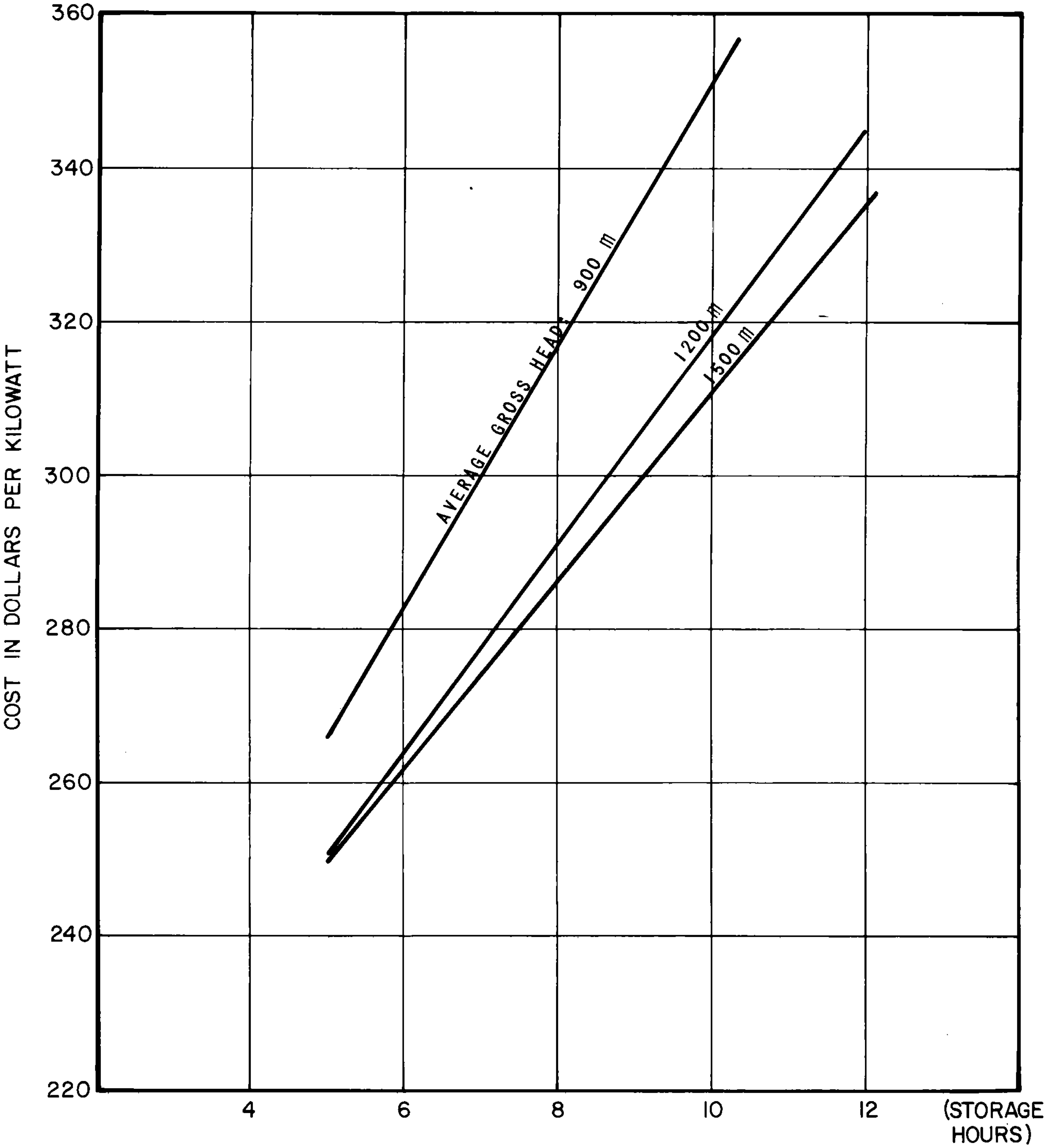


INSTALLED CAPACITY

COST ESTIMATES OF GENERATING CAPACITY
(EFFECT OF CAPACITY)

NOTES:
- MULTISTAGE REVERSIBLE PUMP/TURBINES
- COSTS AS OF JANUARY 1977
- 1200m HEAD
- INTEREST ASSUMED AT 3.8% PER YEAR
- NO INFLATION OR ESCALATION INCLUDED
- SINGLE DROP

MAIN PLATE III-8



INVESTMENT COST ESTIMATES OF ONE DROP, 2000MW SCHEMES
(EFFECT OF STORAGE)

NOTES: - COSTS AS OF JANUARY 1977 PRICE LEVEL

- NO INTEREST DURING CONSTRUCTION OR ESCALATION INCLUDED

MAIN PLATE III-9

relatively flat zone between the 1200 and 1500 m heads.

Finally, an attempt was made to see what happens if the present worth method is used to evaluate the different schemes. Making the assumption that the date of commercial operation for all alternate schemes is the same, the present worth of the annual disbursements has been computed for 9% and 10% interest rates. It can be seen that the P.W. curves show a minimum in the same head range 1200-1500 m (4000-4900 ft).

3.12.2 Effect of Capacity

The effect of a change in capacity on the construction time is presented on Plate III-7. It can be seen that for constant head and storage the smallest capacity plant (1300 MW) requires the shortest construction time.

The present cost curve (Plate III-8) shows a definite advantage in favor of the large capacity scheme (2700 MW). However, as soon as interest during construction is taken into consideration or the present worth method is applied, the minimum investment ($/kW) zone moves close to the 2000-2100 MW area.

3.12.3 Effect of Storage

The effect of storage on the investment cost of a 2000 MW scheme is presented on Plate III-9.

An incremental hour of storage adds an incremental investment of about $13-14/kW in the case of a 1200 m head project.

3.13 Friction Reducing Additives

Water friction reduction possibilities were investigated on recent results where small amounts of polymer were used as an additive. Contacts were made with Nalco Chemical Co., a major producer of polymers. The investigation showed that although some significant reductions were effected (up to 50/60%) all were related to small pipes with one exception of 0.3 m (12 inch) size. These sizes are not comparable to the large sized shaft required for UHPS of 6.0 m (19.7 ft.). This larger size has a much higher Reynolds number with significantly less friction reductions.

3

The overriding consideration, however, is cost. It is estimated that for a 2000 MW, 10 hour storage UHPS plant, the initial treatment with polymer may cost in the magnitude of $400,000,000. Monthly replacement costs can total $5,000,000/yr.

3.14 Heavy Media Fluids

Although the use of a heavy fluid instead of water is technically feasible it too was ruled out on a cost basis. Finely ground ferro-silicon (magnetite), water, and a polymer were considered as a stabilizing agent. In contacts with Dr. Laslo Valentyik of Michigan Technological Institute, an eminent authority on heavy media suspensions, and the Foote Mineral Co., it became evident that the use of this vehicle was impractical. This is due to the fact that $100 must be expended for every cubic meter of lower reservoir excavation reduced. This figure is 400% of the direct cost of a cubic meter of removable excavation, and is therefore impractical. Attempts to find other alternate heavy fluids were unsuccessful.

3.15 Conclusions

It is concluded that geologic siting opportunities do not occur in all regions of the United States. To insure the success of an UHPS it is vital that rock conditions be competent at the depth of UHPS, 1200 m (4000 ft.). In the category of competency are sedimentary rocks that are flat bedded, well lithified, and structurally undeformed. Recommended rocks are limestone, dolomite, impervious sandstone, and pre-Cretacious industrial shales. Seismic risk factors should be considered.

Pump/turbine equipment is in general currently available. The exception is the single drop multi-stage reversible pump/ turbine unit. European manufacturers state they can produce an actual project of the design requirements of this report when required.

There is a definite relationship of the specific cost ($/kW) and the construction time under changing criteria for head, installed capacity, and storage capacity. For heads less than optimum 1250 m (4100 ft) construction period increases and costs ($/kW) decreases. The construction period for installed capacity exceeding 1300 m (4260 ft) increases while cost/kW decreases (present worth remains essentially constant. The construction period increases with increase in storage as does the cost/kW. This cost increase, in the case of a 1200 m (4000 ft) head project approximates $13-14/kW per incremental hour of storage.

A sensitivity analysis of underground rock excavation showed that for increased costs of 25%, 75%, and 100% the project cost increased 8%, 24%, and 32% respectively.

Friction reducing additives and heavy media fluids proved to be impractical.

REFERENCES:

1. "Geological Acceptance Criteria and Review of Siting Opportunities Compressed Air Storage and Underground Hydro Pumped Storage Schemes" by Acres, Aug. 1976.

2. "Recent Rock Pressure Measurements and Their Implications for Dam Building" by Hast Nils and Nilson Tore, Eighth International Congress on Large Dams, Vol. I, Edinburgh, May, 1964.

3. "Rock Engineering for Underground Caverns" by Don D. Deere and others, Underground Rock Chambers, Symposium, ASCE, Arizona, Jan. 1971.

4. Discussion to the article "Tumut 2 Underground Power Plant" by M. S. Vasilescu, Proc. Paper 3835 ASCE Power Division, 1965.

5. "Analysis of Large Scale Non-Coal Underground Mining Methods" by Dravo Corporation for the Bureau of Mines, January, 1977.

6. "Problems Associated with Multi-Stage Reversible Pump-Turbines" by Enrico Malquori, ENEL, Rome, L'ENERGIA ELETTRICA - N-1, 1976.

7. "Further Development on High-Head Reversible Pump-Turbines" by W. Meier, Sulzer-Escher Wyss, Ltd., Zurich, delivered at Edison Electric Institute Hydraulic Power Committee Mtg., Buffalo, NY, May 20, 1976.

8. "Trends in Pump-Turbine design" by I. Swiecicki, Allis-Chalmers, York, INTERNATIONAL WATER POWER & DAM CONSTRUCTION, Jan-Feb. 1977.

9. "Characteristics of High-Head Pumped-Storage Plants by M. C. Jog, Shri G. S. Inst. of Technology and Science, Indore, India, INTERNATIONAL WATER POWER & DAM CONSTRUCTION, May 1976.

4.0 UNDERGROUND HYDROELECTRIC PUMPED STORAGE SCHEMES

In early discussions, representatives of BuRec, DOE and MAIN agreed that the initial analysis of UHPS should be predicated on the following criteria:

Capacity	2000 MW
Head	1200 m (4,000 ft.)
Storage	10 hours

To develop an effective project, it was first necessary to make an equipment study to ascertain equipment available to operate under a 1200 m head and the capacity of the generating unit used. The findings of this investigation are summarized in Section III. The indications led to two types: the so-called tandem type (separate pump and turbine), and the relatively new multi-stage reversible pump turbine units. To employ the type of equipment which is most widely used at the present time in conventional pumped storage; i.e. single stage reversible pump/ turbine, it was necessary to employ a "cascade" two-drop scheme. This would employ a single stage reversible pump/turbine such as the 750 m (2,500 ft.) (Escher Wyss) or 800 m (2,600 ft) (Toshiba) units.

4

Having ascertained available equipment, three schemes surface:

Scheme I - a one-drop arrangement with multi-stage reversible units.

Scheme II - a two-drop "cascade" arrangement with an intermediate reservoir thus requiring two powerhouses both equipped with single stage reversible pump/turbines.

Scheme III - a one-drop arrangement equipped with tandem units consisting of a Pelton turbine coupled with a generator-motor to a multi-stage pump.

The three schemes are shown on Plate IV-1. Descriptions of the selected schemes are detailed in following paragraphs.

4.1 General Design Features

It was assumed that the typical UHPS project would be built at a site where competent geologic conditions exist extending from ground level to below the invert of the deepest structure.

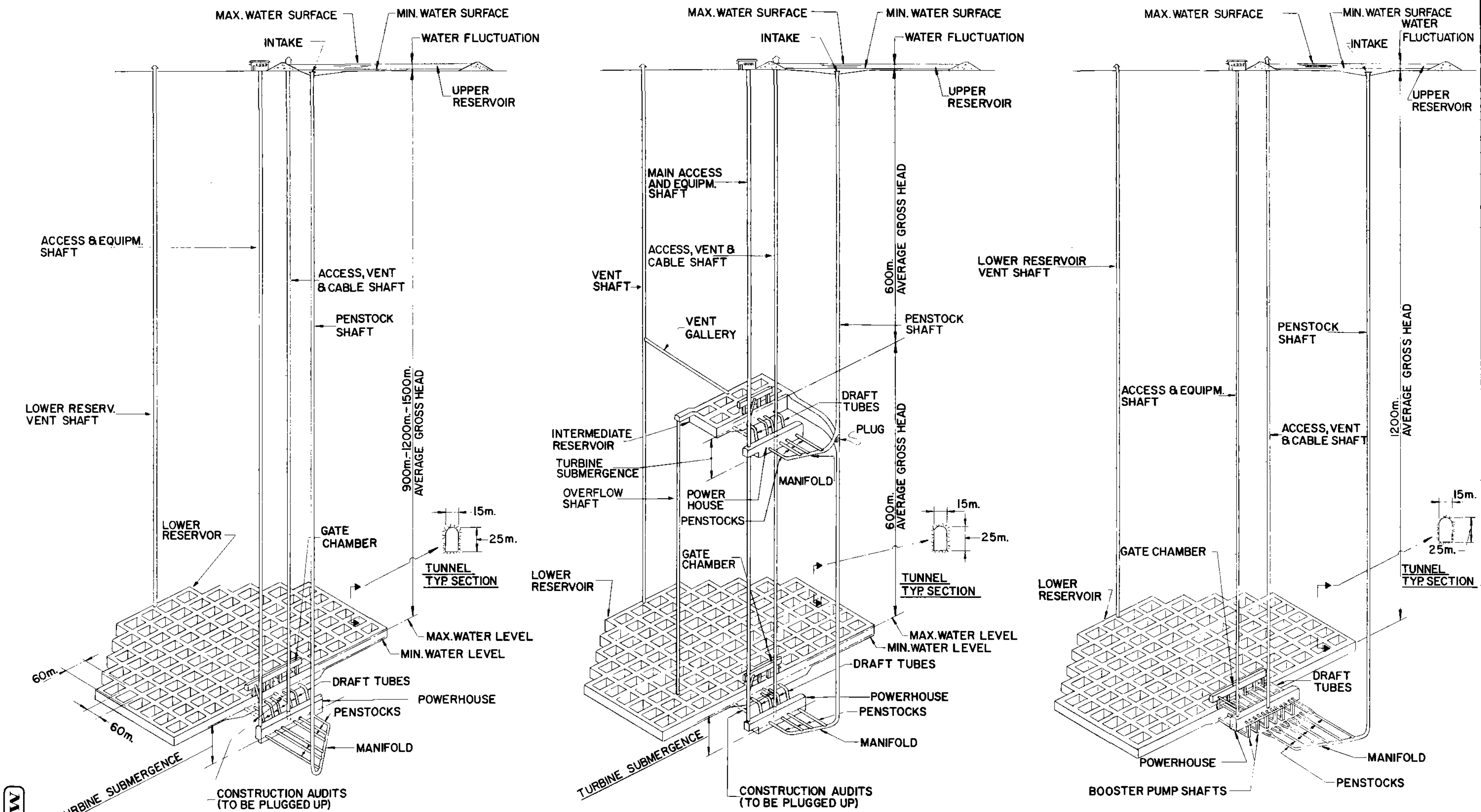
In view of the general character of this study, it was assumed that for all schemes the upper reservoir would be man-made with rock fill from excavations and provided with an artificial lining to prevent seepage.

For all three schemes it was assumed that the waterways system would consist of a single vertical concrete lined penstock-shaft, provided at its upper end with a vertical covered intake (Blenheim-Gilboa type) and at its lower end with a horizontal manifold providing individual connections for each unit.

Although the plant capacity is 2000 MW, it was not considered necessary to provide two penstock shafts and two upper intakes in view of the fact that current pumped storage projects of similar capacity have been designed with only one intake and one penstock-shaft when located in good geologic conditions.

The access to the underground powerhouse is provided in all

UNDERGROUND PUMPED STORAGE SCHEMES



ONE DROP SCHEME
MULTISTAGE REVERSIBLE UNITS

SCHEME I

TWO DROP SCHEME
SINGLESTAGE REVERSIBLE UNITS

SCHEME II

ONE DROP SCHEME
TANDEM UNITS

SCHEME III

MAIN

PLATE IV-1

cases by two concrete lined shafts: a main access and equipment shaft and a cable and access shaft.

The geometry of the lower reservoir is identical for all three schemes.

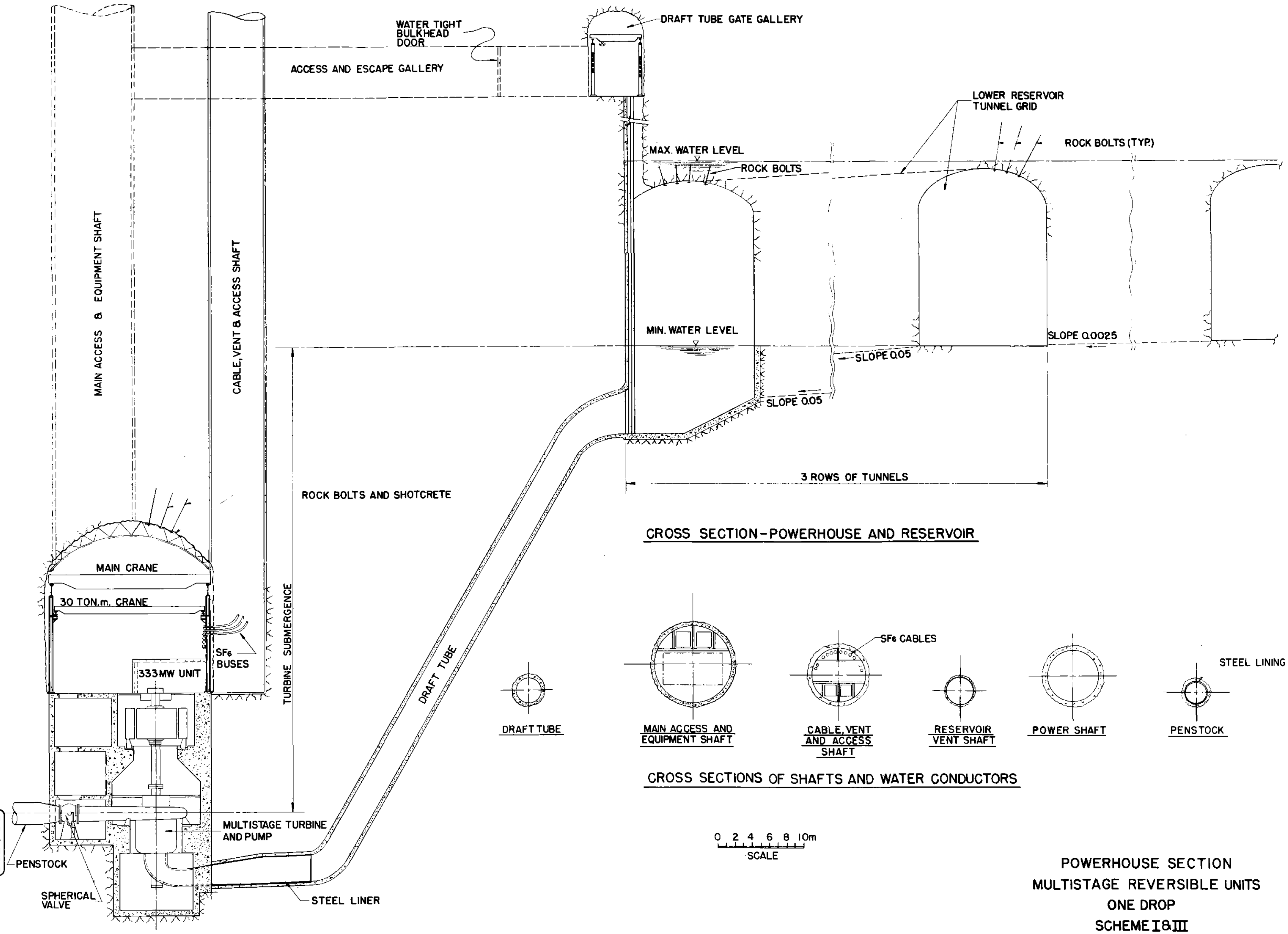
Although no specific optimization of the lower reservoir has been performed, an attempt was made to adopt a geometry which permits the ventilation of the lower reservoir with only one vent shaft. The shape of the lower reservoir was selected to minimize the maximum hauling distance to the hoisting shafts during excavation.

The lower reservoirs consist of a grid of 15 m (49 ft.) wide by 25 m (82 ft.) high tunnels, 60 m (197 ft.) apart. The required volume of the lower reservoir was increased by 3 percent to provide for dead storage. The lower reservoir roof support system would consist of grouted rock bolts for the entire arch area supplemented with wire mesh and shotcrete for 30% of the arch area. For all three schemes it was assumed that 3-phase transformers, one for each unit, would be located in the powerhouse and that the high voltage leads would consist of SF_6 gas insulated bus.

4.2 Scheme I - 2,000 MW (6 Units), 10 Hr. Storage One-Drop, Multi-Stage Reversible Units

This scheme, presented on Drawings Pl. IV-1, Pl. IV-2, and Pl. IV-3, develops 2,000 MW with six 333 MW multi-stage reversible units.

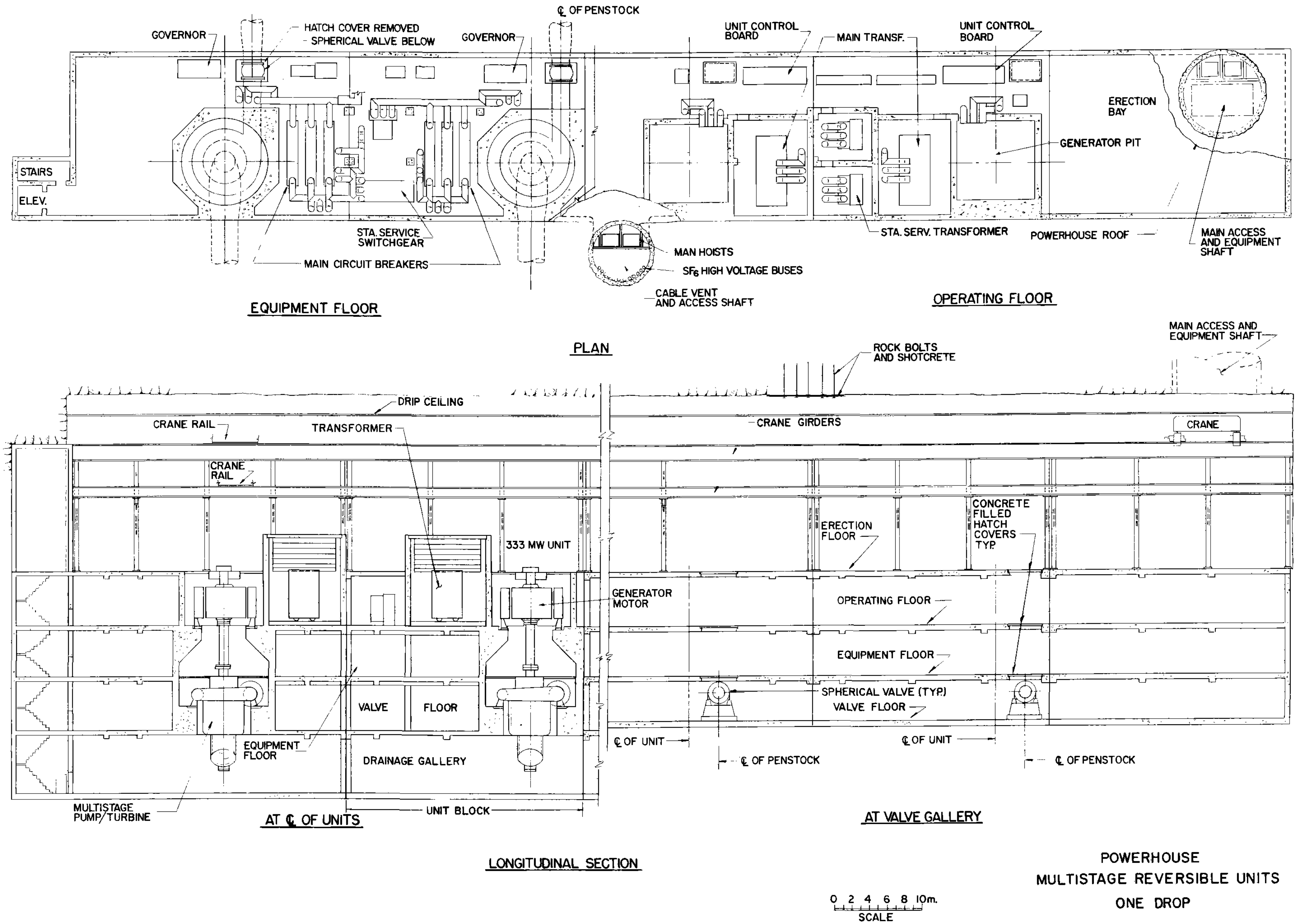
Six units have been proposed for this 2,000 MW plant bearing in mind that these units being without wicket gates will have to operate at full load. Larger size units were considered less



POWERHOUSE SECTION
MULTISTAGE REVERSIBLE UNITS
ONE DROP
SCHEME I & III

MAIN

PLATE IV-2



POWERHOUSE
MULTISTAGE REVERSIBLE UNITS
ONE DROP
SCHEME I & II

MAIN

PLATE IV-3

attractive from the system operation point of view.

333 MW units (514 RPM) correspond to a physical increase of the size of the Chiotas 150 MW machine by one-third and only a 10% increase in material stresses.

Each unit is provided with a spherical valve located in the powerhouse cavern on the high pressure side.

On the low pressure side the units are connected to the lower reservoir through individual inclined draft tubes.

4

As can be seen on drawing Pl. IV-2, due to submergence requirements the powerhouse cavern has to be located significantly deeper than the lower reservoir. In the case of this scheme the minimum required submergence is around 55 m (180 ft.).

A draft tube gate gallery is provided above the lower reservoir connecting to the main access shaft.

The main access shaft has an interior diameter of 9 m (30 ft) provided at its top with a hoist capable of handling the heaviest and largest equipment item which may be shipped in one piece.

The cable shaft has an interior diameter of 6.2 m (20 ft.).

The powerhouse cavern is about 19 m (62 ft.) wide, 37.5 m (123 ft.) high, and 194 m (636 ft.) long.

As can be seen on drawing Pl. IV-3, each unit block contains one pump/turbine unit and its 3-phase transformer.

The vertical generator/motor connected to each pump/turbine is rated at 370 MVA and 514 RPM.

Although these 370 MVA, 514 RPM units are larger than any combined MVA and RPM units now installed, discussions with manufacturers confirm that they can be designed using existing manufacturing methods.

The preferred pump starting method for these units is synchronous starting by a static converter inverter system. Synchronizing in the generate mode can be attained either by using the spherical valve bypass for speed control or by reversing the pump start equipment.

The transformers proposed are conventional oil-filled units, forced-water cooled, installed in enclosures and protected by a CO_2 fire protection system. The transformers are connected on the high voltage side in pairs with the gas insulated bus eliminating all open, non-insulated high voltage connections.

The design of the auxiliary electrical and mechanical equipment is similar to that required for powerplants located 600 m or more underground.

The following are the estimated characteristics of these multi-stage reversible pump/turbines:

Turbine efficiency	89.5%
Turbine flow (average head)	32.9 m^3/sec. (1160 cfs)
Pump efficiency	89.5%
Pump flow (average head)	27.5 m^3/sec. (970 cfs)

There is very little information available regarding how fast these multi-stage reversible units can reach full load generation from standstill.

If the units start in the generating mode by reversing the pump start equipment, the full load could be reached in about 10 minutes.

However, tests performed at an existing installation with multi-stage reversible units demonstrated that the units can be started in the generating mode in a much shorter time by using the spherical valve.

It should be noted that at least one manufacturer has in an advanced design stage a multi-stage reversible unit of about the size and head used in this study, provided with wicket gates.

Obviously, if wicket gates are provided the generating starting time of this unit will be very close to that of the single runner reversible units.

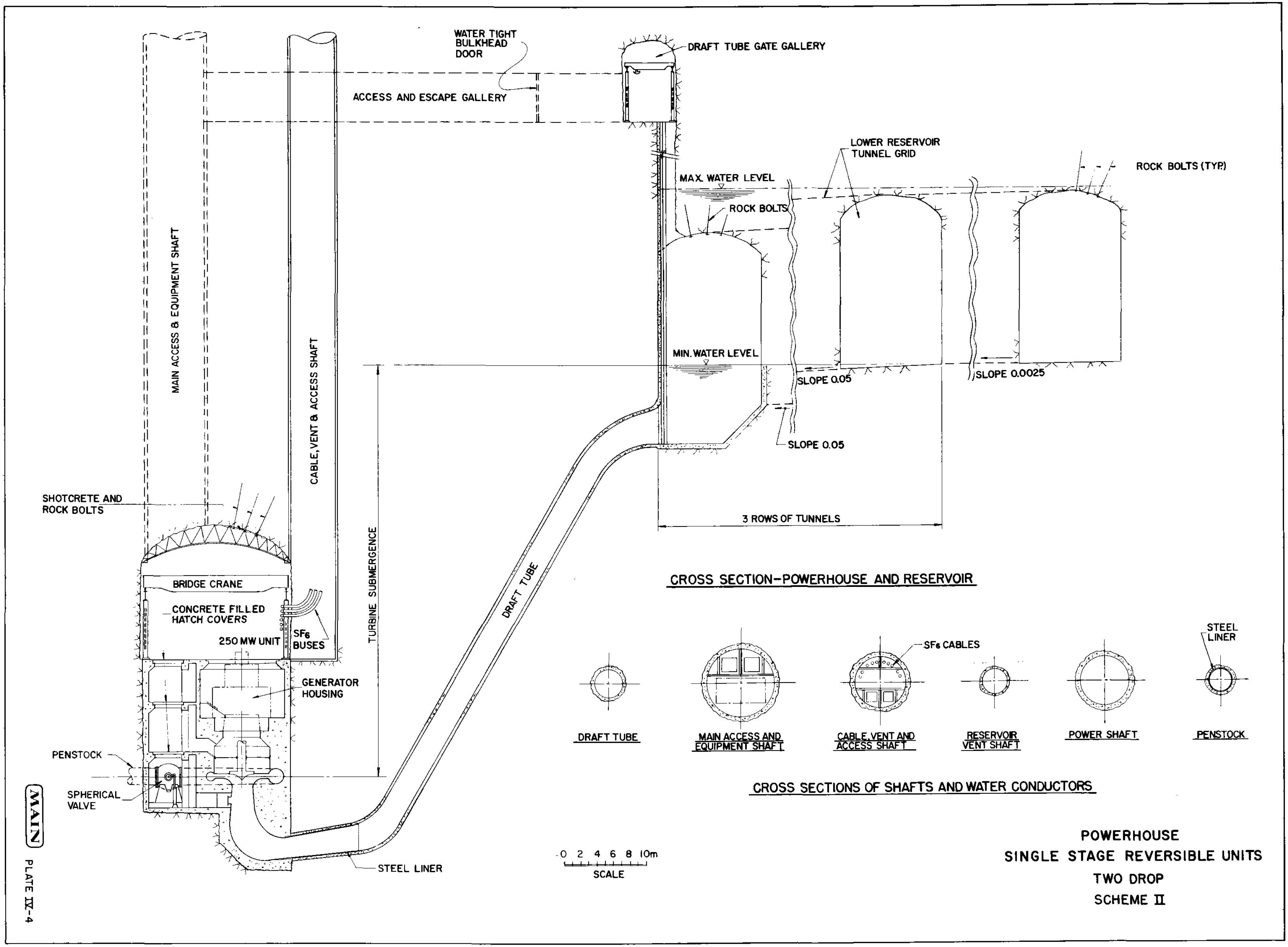
The time needed for a unit to reach full load pumping for this study was estimated at about 8 minutes.

4.3 Scheme II - 2,000 MW (2 x 4 Units), 10 Hr. Storage Two-Drop, Single-Stage Reversible Units

This scheme is presented on drawings Pl. IV-1, Pl. IV-4, and Pl. IV-5. It develops 2,000 MW with 8 - 250 MW single-stage reversible units located in two powerhouses, one at about 600 m (2,000 ft.) depth and the other at 1,200 m (4,000 ft.) depth.

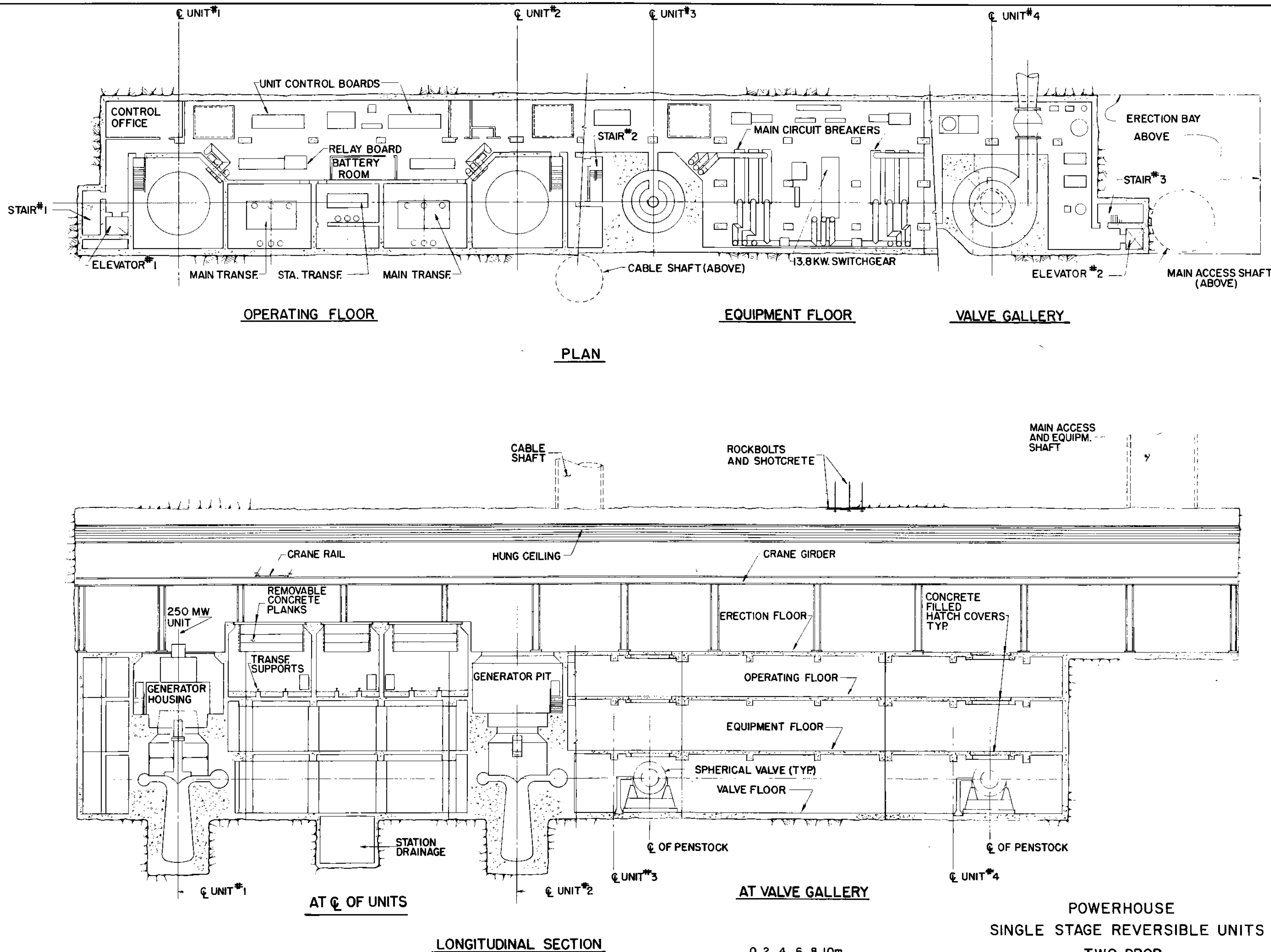
The lower reservoir has the same volume, dimensions and shape as Scheme I.

However, this "two-drop" arrangement requires an additional



MAIN

PLATE IX-4



POWERHOUSE
SINGLE STAGE REVERSIBLE UNITS
TWO DROP
SCHEME II

MAIN

PLATE IV-5

reservoir at the intermediate powerhouse level to allow the two powerplants to operate in series (cascade).

Without this intermediate reservoir the operation of the two powerplants would have to be perfectly synchronized, which is practically impossible.

A necessary requirement of this scheme is that during pump or turbine mode at full load, the intermediate reservoir must be kept half full. If it were kept full, then any forced reduction in output of the lower plant in the turbine mode would cause an outage in the upper plant to prevent overfilling. In the pump mode any forced reduction in the upper plant would cause shutdown of a unit in the lower plant. Similar considerations apply if the intermediate reservoir is kept empty.

It was then decided to provide Scheme II with an intermediate reservoir which in the event of an emergency shutdown of one plant (either upper or lower) will permit the other plant to operate for 15 minutes. This also means that under normal conditions, one hour is allowed between starting a unit and starting a counterpart in the other plant. However, it should be understood that any forced outage of a 250 MW unit in either plant with a duration of more than one hour will force the shutdown of its counterpart unit in the other plant resulting in a forced outage of 500 MW.

In conclusion, the intermediate reservoir volume up to its maximum free water level assumed in this study corresponds to 2 hours of full load generation by one machine.

For ventilation the intermediate reservoir is connected to the lower reservoir vent shaft through a vent gallery (see drawing Pl. IV-1).

The intermediate reservoir will be provided with an emergency overflow system.

It has been the Federal Energy Regulatory Commission's policy to require all pumped storage projects built during the last decade to incorproate an emergency spillway in the upper reservoir design. This emergency spillway must be able to discharge the flow corresponding to the entire plant pumping output for that specific head.

The overflow shaft has been provided between the intermediate reservoir and the lower reservoir (see drawing Pl. IV-1). Special attention must be paid to the design of this overflow lining which will eventually have to be able to handle a flow of approximately 200 m^3/sec. (7,000 cfs), for a 600 m (2,000 ft.) depth.

Each unit is provided with a spherical valve located in the powerhouse cavern on the high pressure side.

On the low pressure side the units are connected to the lower reservoir through individual inclined draft tubes.

As can be seen on drawing Pl. IV-4 for this scheme, due to submergence requirements, both powerhouse caverns have to be located significantly deeper than the lower reservoir and the intermediate reservoir. For this scheme the minimum required submergence is around 60 m (197 ft.).

A draft tube gate gallery is provided above each reservoir with connection to the main access shaft.

The main access shaft, 8.5 m (28 ft.) interior diameter and the high voltage bus shaft, 6.2 m (20 ft.) diameter, serve both powerhouses.

Each powerhouse cavern is about 21.6 m (71 ft.) wide, 41.0 m (135 ft.) high, and 126.0 m (413 ft.) long.

As can be seen on drawing Pl. IV-5, each unit block contains one unit and its 3-phase trnasformer.

The vertical generator/motor connected to each pump/turbine is rated 278 MVA and 450 RPM.

The starting equipment, transformer high-voltage buses, and all auxiliary equipment are practically of the same type as described under Scheme I.

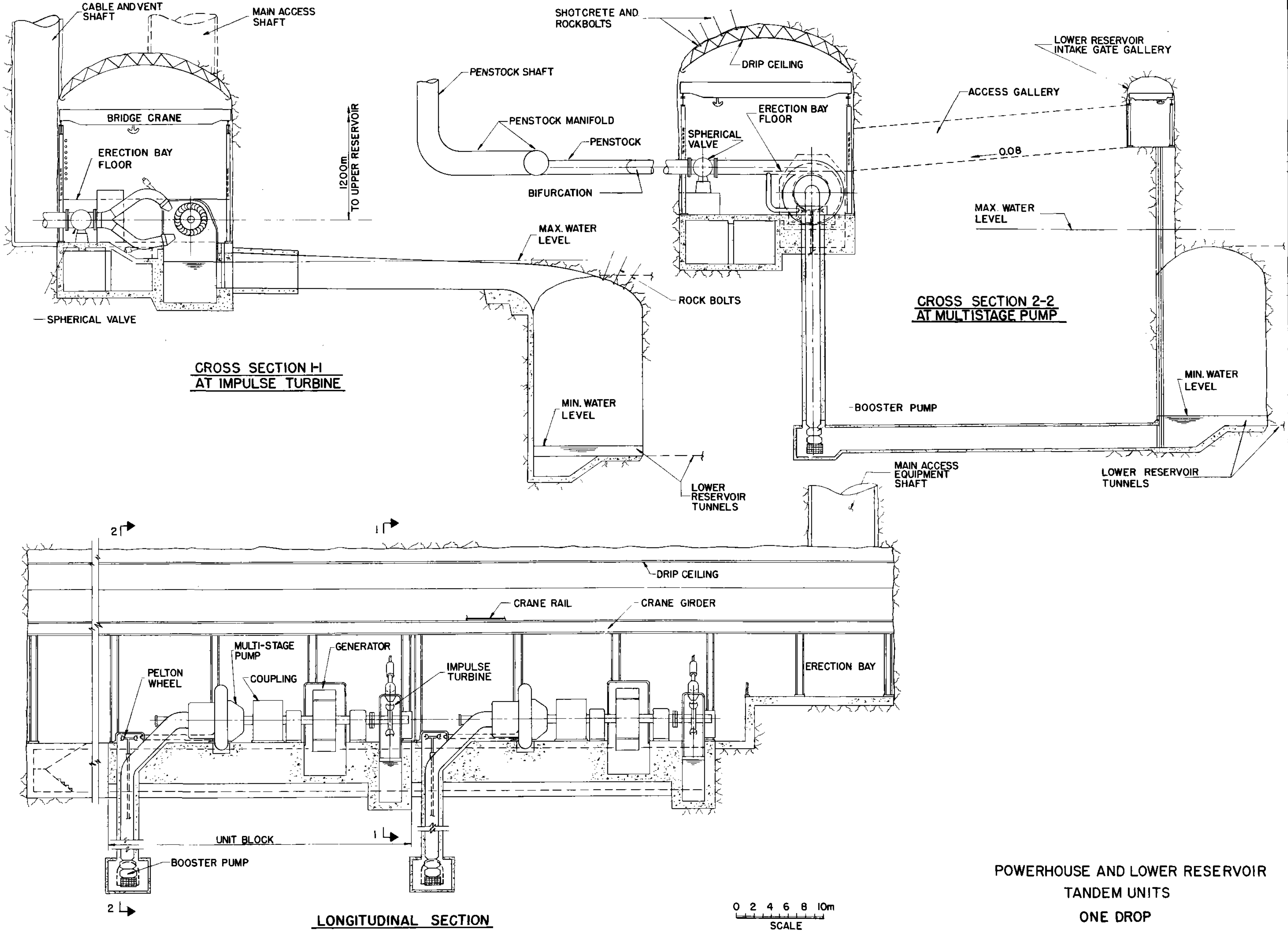
The following are the assumed characteristics of the single-stage reversible pump/turbines:

Turbine efficiency	91%
Turbine flow (average head)	47.1 m^3/sec. (1660 cfs)
Pump efficiency	91%
Pump flow (average head)	41.5 m^3/sec. (1460 cfs)

The single stage reversible pump/turbines will have wicket gate regulation and will be capable of operation in the generating mode from half-load to full-load.

From standstill the unit can reach full load generation in 3 minutes and full load pumping in 10 minutes.

Turn around from full load pumping to full load generation can be made in 3 minutes.



POWERHOUSE AND LOWER RESERVOIR
TANDEM UNITS
ONE DROP
SCHEME III

MAIN

PLATE IV-6

4.4 Scheme III - 2,000 MW (6 Units), 10 Hr. Storage, One-Drop, Tandem Units

This scheme, presented on drawing Pl. IV-1 and Pl. IV-6, develops 2,000 MW with six 333 MW tandem units.

Each unit consists of a multi-stage pump, coupling, generator/ motor and impulse turbine.

In order to locate the turbine above maximum tailwater level and still provide submergence for the pump, a very long intermediate mainshaft would be required. To avoid this and to keep the height of the powerhouse cavern to a minimum, a booster pump driven by a small Pelton wheel is provided to supply NPSH to the multi-stage pump inlet. The same arrangement is used at Motec in Switzerland. In addition to the normal spherical valve at the turbine inlet, another is required at the pump discharge.

As can be seen on drawing Pl. IV-6, the powerhouse cavern is located above the lower reservoir level.

On the lower pressure side each unit is connected to the lower reservoir through two galleries. One discharge gallery connects the Pelton turbine pit with the lower reservoir, the other gallery feeds lower reservoir water to the booster pump.

The lower reservoir intake gate gallery located above the lower reservoir level is connected to the powerhouse cavern.

The powerhouse is connected to the surface through two shafts, the main access and equipment shaft (9.0 m interior diameter) and the high voltage bus and ventilation shaft (6.2 m interior diameter).

The powerhouse is about 24.4 m (80 ft.) wide, 34.0 m (112 ft.) high, and 275.0 m (902 ft.) long.

Each powerhouse unit block contains one tandem unit and its 3-phase transformer.

The horizontal generator/motor connected to each pump is rated 370 MVA and 514 RPM.

The transformers, high voltage buses and all auxiliary equipment are similar to those described under Scheme I.

4

Operationally, Scheme III has the most flexible plant arrangement allowing turbine operation from no load to full load.

The following are the assumed characteristics of the Pelton units and the multi-stage pumps:

Pelton unit efficiency	91.5%
Pelton unit flow (average head)	32.2 M^3/sec. (1140 cfs)
Pump efficiency	89.5%
Pump flow (average head)	27.15 m^3/sec. (960 cfs)

From standstill the machine could reach full load generation or full load pumping in 3 minutes.

Turn around from either mode can be made in about the same time.

It should be mentioned that the above starting times correspond to the U. S. practice of synchronizing the units. By adopting European practices this starting time could be cut to less than half. The booster pump efficiency will be at least as high as that of the main pump.

4.5 Upper Reservoir

The upper reservoir will be similar to that of conventional pumped storage. For this study the typical dike section will be rockfill, utilizing excavation from the underground structures. The reservoir interior will be lined with a protective layer to prevent leakage. Typical details are depicted on Pl. IV-7. The dike height will be 22 m (72 ft.).

4.6 Cost Estimating Procedure

One of the main objectives was to try to determine as realistically as possible the estimated cost of these UHPS projects.

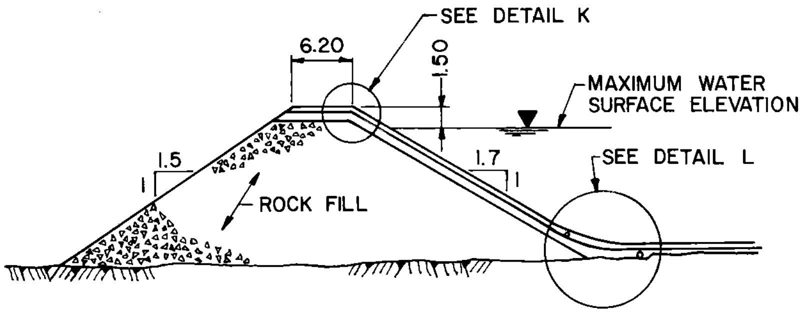
The procedure followed in estimating the cost of the underground civil works is covered in paragraph 3.7 and detailed in Appendix II.

Additional considerations are covered below:

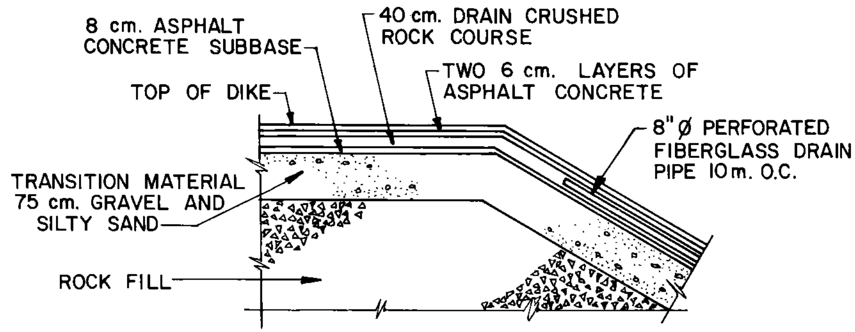
1. The water intake in the upper reservoir and the powerhouse items other than excavation are estimated on the basis of reported costs of similar completed structures.

2. The cost of the main electro-mechanical equipment is based on recent quotations from manufacturers. For the multi-stage reversible pump/turbines estimated prices were obtained from Sulzer-Escher-Wyse for the Chiotas unit (150 MW, 1000 m head) adjusted to equipment recommended herein.

3. Contingencies of 25% is applied to all underground civil works and 10% to electro-mechanical equipment.



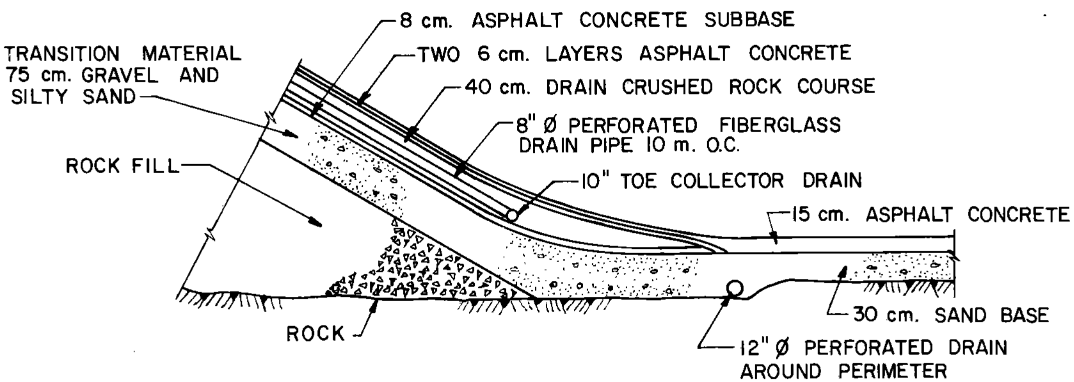
TYPICAL SECTION
THRU UPPER RESERVOIR DIKE
NO SCALE



DETAIL K
NO SCALE

NOTES:

1. ROCK FILL DAM BUILT WITH ROCKS FROM THE LOWER RESERVOIR EXCAVATION.
2. DAM HEIGHT 22 m. ±



DETAIL L
NO SCALE

UPPER RESERVOIR
TYPICAL SECTIONS

MAIN

PLATE IV-7

The engineering, supervision and overhead cost is 12% of the total cost (including contingencies.)

4.6.1 Design Criteria

Any cost estimate starts with some quantities which are a function of the physical dimensions of the different project structures. For this reason it is important to know if the design was based on realistic, pessimistic or optimistic assumptions.

An overly optimistic approach to geologic conditions coupled with optimistic assumptions concerning productivity of labor and equipment all compounded by an inadequate contingency factor can only result in gross underestimation of project cost.

An overly conservative estimate can result when the abovementioned chain of assumptions are made in the opposite direction.

In the case of these UHPS schemes in view of the fact that this study is not related to any specific site it was considered acceptable to assume that the entire upper reservoir is manmade and provided for its entire area with an impervious membrane.

The individual penstocks part of the upstream horizontal manifold were provided with steel lining for a length of approximately 150 m (490 ft.) upstream from the powerhouse wall.

An item which was added as a design decision was "construction adits". Under this item were included construction galleries between the access shafts and the lower reservoir, construction adits for the powerhouse excavation, heavy skip loading installations, etc.

Also here, as general assumptions it should be mentioned that due to the character of this study some of the items included in the FERC system of cost estimates had to be estimated without any real basis. Among these are: Land & Land Rights, Reservoir Filling, Roads & Bridges.

4.6.2 Scheme Costs and Schedules

Summary Table (IV-1 sets forth the total construction cost (direct), $/kW, and construction periods for the several schemes. Detailed costs are set forth in Appendix I. An in-depth cost development of excavation for the underground reservoir is found in Appendix II. Detailed construction schedules are shown in Appendix III.

4.6.3 Daily Round Trip Efficiency

Waterways of the three schemes herein are designed so that the same RTE results for each. The RTE considering transformers, motor, pump and conduit losses on the pumping cycle; and transformer, generator, pump losses on the generating cycle result in 67 to 75% efficiency depending on particular economic consideration of the system involved.

TABLE IV-1

INVESTMENT COST & CONSTRUCTION TIME OF UHPS SCHEMES

No.	SCHEME	TOTAL COST ($x10^6)	$/kW (Incl. storage)	% of Scheme I	CONSTRUCTION TIME First Unit Com. Oper.	Last Unit Com. Oper.
I	2000 MW (6x33) 1200 m; 10 hrs.	636	318	100	6 yr + 9 mo	7 yr + 7 mo
II	2000 MW (8x250) 2x600m; 10 hrs	658	329	103	7 yr + 1 mo	7 yr + 6 mo
III	2000 MW (6x333) 1200 m; 10 hrs. tandem	693	347	109	6 yr + 9 mo	7 yr + 7 mo
IV	2000 MW; (6x333) 500 m, 10 hrs.	623	311	98	7 yr + 2 mo	8 yr
V	2000 MW (6x333) 900 m, 10 hrs.	704	352	111	7 yr + 6 mo	8 yr + 4 mo
VI	2700 MW (8x337) 1200 m, 10 hrs.	815	302	95	7 yr + 11 mo	9 yr + 3 mo
VII	1300 MW (4x325) 1200 m, 10 hrs.	454	350	110	6 yr + 5 mo	6 yr + 11 mo

NOTE: Based on unit prices as of January, 1977
Time counted from the award of the Civil Contract
Interest during construction (AFDC) and escalation not included

5.0 UHPS IN COMBINATION WITH UNDERGROUND NUCLEAR POWER PLANTS

5.1 General

The design and construction of UHPS and underground nuclear power plants in combination with UHPS presents no insurmountable technological problems. Engineering modifications, e.g., ventilation, drainage, and circulation systems applicable to the nuclear plant can be satisfactorily coped with. The major impediment is cost. An underground nuclear power plant is more costly to construct than a surface plant. Previous studies on this subject indicate that increased cost can range between 20 to 40%. An example of added costs is the underground plant excavation (exclusive of shafts) that could involve 400,000 m^3 (523,000 c.y.), for a 1000 MW plant, at an approximate cost of $6 to $8 million. However, partially offsetting this expense are a number of positive factors: definite environmental gains (not susceptible to monetary evaluation in all instances); use of common facilities, e.g., sub-stations, switch yards, transmission facilities, water reservoir, and common operating personnel and facilities, excluding licensed nuclear plant operators.

Land area within the United States, as a whole, for mined rock caverns siting is considered to be substantially less than for cut and cover siting. This factor, because of cost saving, may lead to the opting for cut and cover in spite of lesser safety benefits.

It is noted that the Nuclear Regulatory Commission (NRC) has recently formally rejected a petition by the Ralph Nadar affiliated Public Interest Research Group and several other antinuclear organizations to locate reactors underground (Nucleonics

Week, April 27, 1978 pg. 12). NRC stated there was insufficient supporting material to indicate that underground siting should be made mandatory.

5.2 <u>Advantages of Underground Nuclear Plants (in rock)</u>

The advantages of Underground Nuclear Plants (UNP) in rock are many:

a. Containment of radioactive gasses and liquids.

b. Protection from external hazards.

c. Limited wartime exposure.

d. Limited seismic vulnerability because of bracing effect of surrounding rock and less ground motion in rock.

e. Joint use of facilities and personnel at savings.

f. Reduction of the construction and operational impact upon the environ from two plants to one.

g. A possibility for significant economics exists to the nuclear plant which has limited ability to follow very large step changes in system loads. The UHPS follows these load changes easily. It, therefore, increases the power system's ability to follow load changes and lessens the need for this flexibility in the nuclear plant. Thus, the nuclear plant can be designed for a steady output and its control system simplified at a savings.

5.3 Disadvantages of Underground Nuclear Plants (in rock)

Countering the advantages stated above are negative factors that need be weighed in the decision-making process:

a. Additional cost (20 to 40% increase over a surface plant.

b. Vulnerability of surface heat sink to malicious or wartime acts.

c. Escape of containment sump water.

d. Due to anticipated increase in design efforts resulting from modifications, various licensing analysis, and slower construction progress the overall time prior to power on line is greatly extended. It is anticipated that this could reach 3 to 5 years.

e. Operational activities of UNP are more complicated. This involves maintenance and repair of plant components; difficulties in removal of large equipment items and spent fuel casks; resulting potential increase in downtime and reduced plant capacity factor.

f. Plant decommissioning, by any of the conventional methods, would have increased costs.

g. Under circumstances of total failure (accident) it could induce stresses in the rock possibly negating the operation of the UHPS resulting in double jeopardy.

5.4 Technical Consideration

5.4.1 General

The underground nuclear plant, not requiring an operating hydraulic head as in the case of UHPS, is relieved of many of the former's impositions. UHPS is similar in pattern to surface conventional hydro pumped storage; so too is an underground nuclear plant similar to the surface type. For this reason the cavern pattern is laid out similar to the surface plant.

5.4.2 Siting Consideration

Reports on underground nuclear plants establish the premise that depth to bed rock is critical in determining the practicality of rock cavern siting. Design requirements necessary to insure stability of the cavern require undisturbed rock approximately 1½ times the span of opening above the top of the cavity. The proposed reactor building cavity for which a suggested layout has been prepared was 38 m (125 ft.) which would result in a competent rock cover mantle of 60 m (200 ft.).

Rock-type and structure are critical in the feasibility of rock cavern siting. Competent rock is vital to the feasibility of a project. Bed thickness, rock structure, excessive jointing, weak partings, were considered defects calling for unsuitability of the site.

It is worthy to note that a review of reports on the subject, as well as Safety Analysis Reports, indicated that only 20 to 25% of considered sites survived while over 80% of the sites were found suitable for cut and cover underground siting.

5.4.3 Main Condenser System Considerations

It is assumed that the cooling water system would be a closed loop system independent of water flow patterns of the pumped storage unit. One concept is to install a hydraulic turbine/generator at the bottom end of the standpipe with the cooling water passing through the hydraulic turbine prior to passing through the condenser prior to discharging into a collection sump. The heated cooling water is then pumped to a spray cooling pond located on the surface by circulating water pumps.

The advantage of this arrangement is that the electrical output of this system could be used to reduce the pumping power consumption by the circulating pumps and it would allow the use of low pressure condensers.

5

5.4.4 Heat Rejection

A station's major heat rejection duty will be approximately 6.6×10^9 Btu/hr. from the main condenser where the exhaust steam from the turbine/generator set is condensed. Proposed systems for cooling circulating water, which is not safety related, could be cooling towers, cooling ponds and canal cooling.

A second heat rejection system will be necessary for the nuclear plant reactor components and will be a safety related system. During normal operation, shutdown, or after an accident, heat from the core, plant accessories, and containment heat must be rejected to a suitable heat sink. This can be a cooling tower, lake, pond, etc. but it must be designed against any possibility of failure and in most cases, be redundant. The point of heat discharge is designated as the heat sink.

The ultimate heat sink is on the surface and vulnerable to sabotage or wartime munitions attack. This vulnerability would seriously impact the gains achieved by placing a nuclear power plant underground.

The above noted heat rejection systems limit the aesthetic gains achieved by locating the nuclear power plant underground.

5.4.5 Containment of Liquids

As previously discussed, to justify the siting of nuclear power plant underground requires reliable sealing of all passages and accesses during an emergency. Otherwise the contention of assuring containment of radioactive gasses, within the underground cavity is not valid and the radioactivity will be released to the environs.

Plant ventilation shafts are another type of passage required for the underground nuclear unit. Large diameter butterfly valves are commercially available which are suitable for the pressure and temperature considered for this application. Proposed valve closure components have been successfully applied in the weapons testing programs at the Nevada Test Site and considerable design criteria is available for similar applications.

5.4.6 Earthquake Design for Structure

Since an earthquake is the most outstanding common-mode initiator of accidents, earthquake resistant design has been the major determining factor in plant siting and economics. Underground siting has been considered as a means by which the seismic vulnerability of nuclear power station may be reduced. The supporting premise is that the damaging earthquake mechanism (ground motions) is reduced at depth. The effects of earthquakes, both overseas and in the United States, have been studied and measurements have been recorded. The result is general agreement that for the same earthquake at the same location, ground motion is less in bedrock than on the surface.

It is further considered that an underground cavern will respond as a more rigid structure because of the bracing effect due to the surrounding bedrock.

While substantial reductions in construction cost savings may not materialize, it is expected that a modest reduction in seismic vulnerability will be achieved.

5.4.7 Ground Water Contamination

There are several scenarios for which it is envisioned that contaminated spray water can leak directly into and contaminate ground water.

Our methodology is that the containment spray water becomes contaminated with the soluble radionuclides during the early stages of the core meltdown. When breaching of the containment by the core occurs, followed by the escape of the contaminated spray water into the ground, the possible mixing of contaminated spray water with ground water exists. It appears that with the likelihood of this escape of sump water into the ground following core meltdown, ground water contamination may be more severe in an underground plant than a surface plant.

5.5 Typical Combination of UHPS and Underground Nuclear Plant

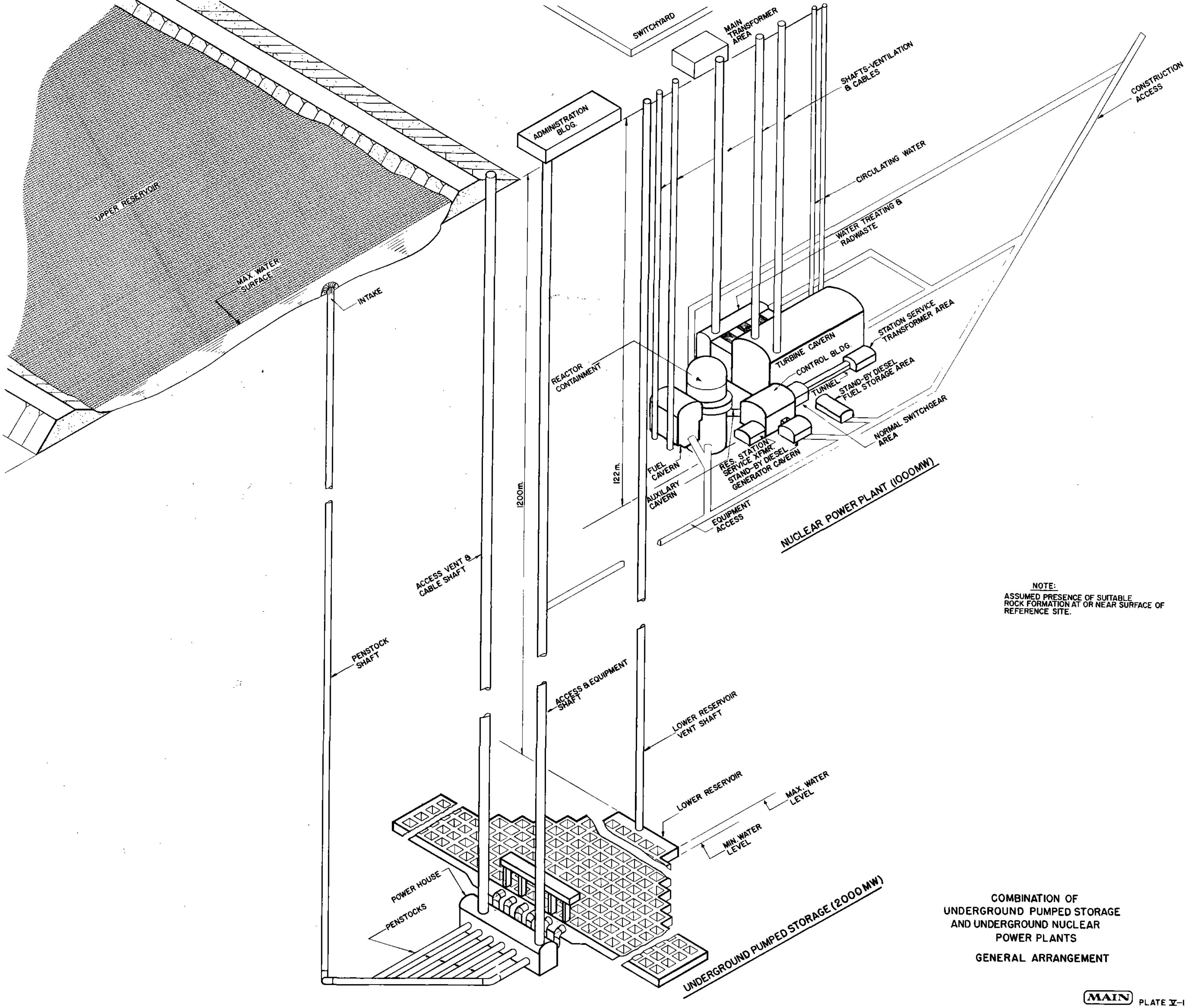
In order to demonstrate the potentials of combining UHPS and an underground nuclear plant a suggested "typical" arrangement has been prepared. This combination is shown on Plates V-1 through V-3. The UHPS is representative of the proposals of this report.

5.6 Underground Nuclear Power Configuration

Arrangement of the underground nuclear power plant will be similar to that of a surface plant with the exception that the separation distances between the major equipment systems located in caverns may vary to assure mined rock stability. The containment cavity is 38 m (125 ft.) in diameter and 60 m (197 ft.) high with an elliptical roof. The volume of the containment is 66,000 m^3 (87,000 c.y.).

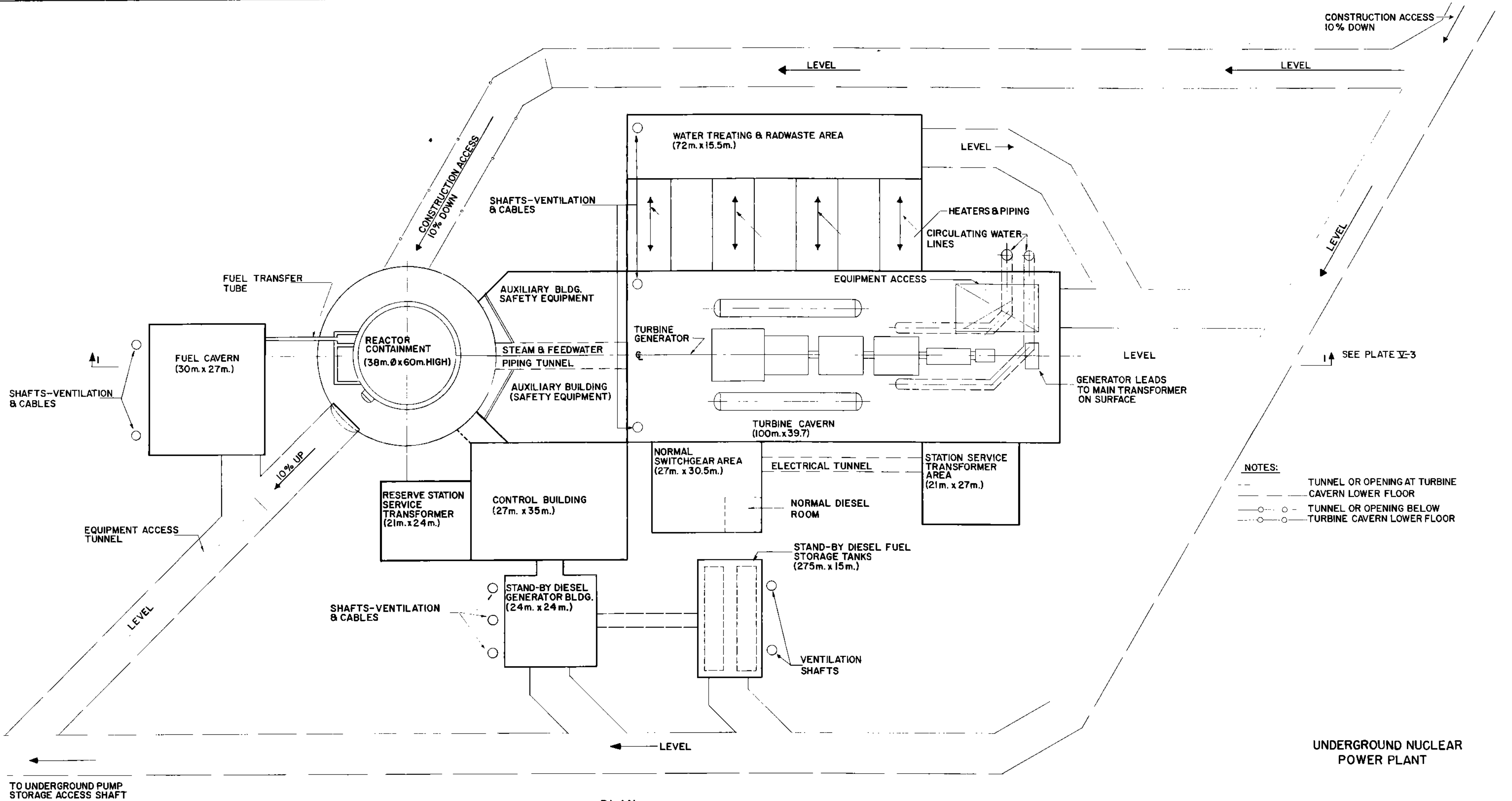
The turbine cavern will have a dished or horseshoe shaped cross section with a span of 40 m (131 ft.), 39 m (128 ft.) high, and 100 m (328 ft.) in length. This represents a volume of 150,000 m^3 (195,000 yds^3).

The volumes of the balance of the cavities are as follows:



COMBINATION OF
UNDERGROUND PUMPED STORAGE
AND UNDERGROUND NUCLEAR
POWER PLANTS

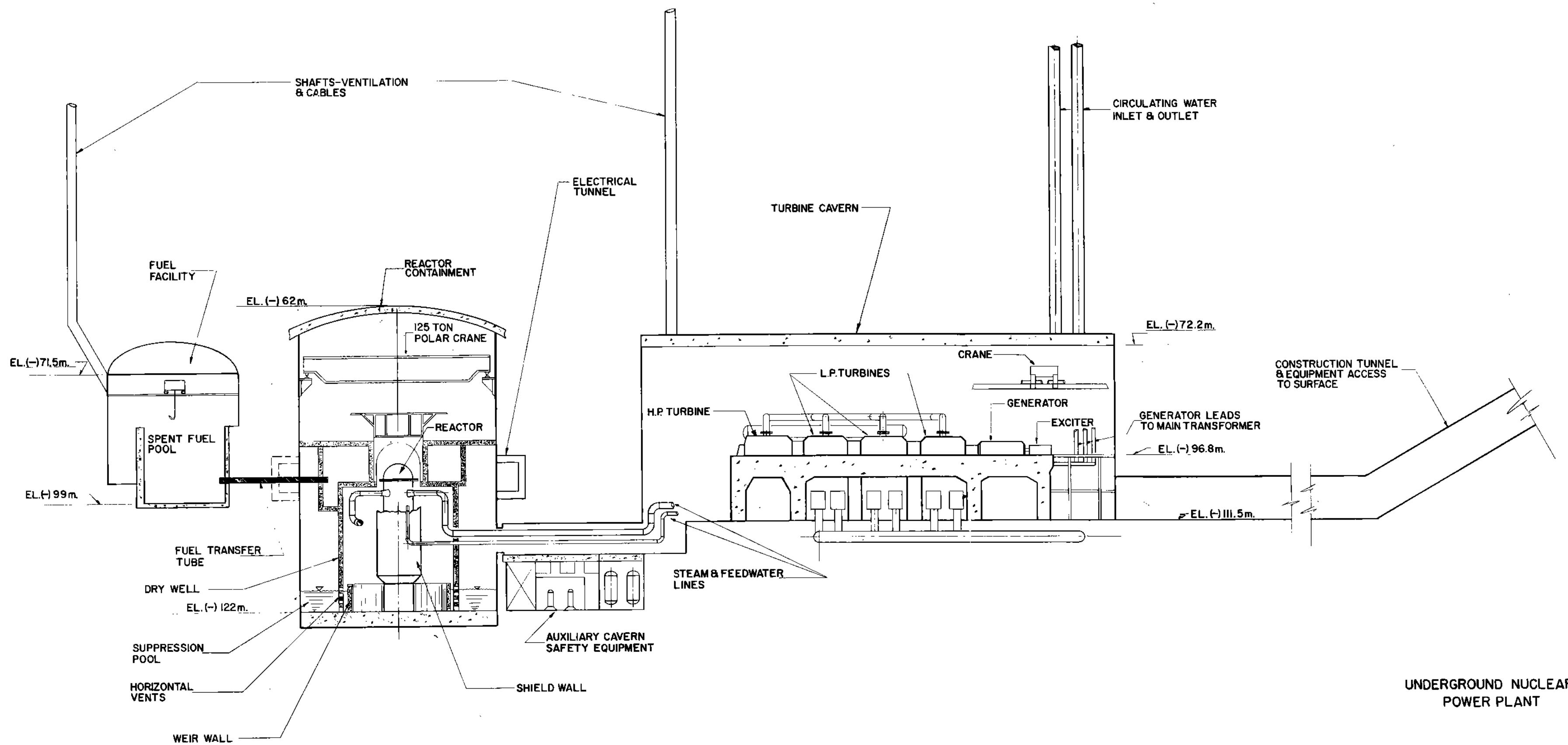
GENERAL ARRANGEMENT



PLAN

UNDERGROUND NUCLEAR
POWER PLANT

MAIN PLATE V-2



UNDERGROUND NUCLEAR POWER PLANT

SECTION I-I (SEE PLATE V-2)

MAIN PLATE V-3

CAVITY VOLUMES

1.	Radwaste and Water Treatment	- 48,600 M^3	(63,180 yd)
2.	Spent Fuel	- 24,300 M^3	(31,590 yd)
3.	Auxiliary (Safety Equipment)	- 24,000 M^3	(31,200 yd^3)
4.	Control	- 23,600 M^3	(30,700 yd^3)
5.	Stand-by Diesel Generator	- 4,000 M^3	(5,200 yd^3)
6.	Normal Switchgear	- 7,320 M^3	(9,500 yd^3)
7.	Station Service Transformer	- 5,670 M^3	(7,370 yd^3)
8.	Reserve Service Transformer	- 5,040 M^3	(6,550 yd^3)
9.	Stand-by Diesel Fuel Storage	- 4,130 M^3	(5,440 yd^3)
	Excavated Mined Cavity, subtotal	-362,660 M^3	(471,460 yd^3)
	Assume 10% Miscellaneous Excavation for Tunnels, etc.	- 36,300 M^3	(47,190 yd^3)
	TOTAL	398,960 M^3	(518,650 yd^3)

Underground assembly of the system not only would involve more mechanical congestion, but more detailed assembly would have to be done in place within the chambers. The sequencing of construction and assembly activities becomes an even more important consideration in plant design. In the underground environment, a delay in the delivery of a single component could conceivably bring some assembly activities to a halt. All these factors could impact and delay construction schedules.

Engineering, licensing, and field supervision costs for a complete underground nuclear plant are expected to double those for a surface plant of similar design.

The total impact of the above increases could add 20 percent to the present day cost for a surface plant.

Additional cost increases would occur due to an extended schedule and have a corresponding effect on escalation and AFDC. These factors could result in a total cost increase of 30 to 40 percent for siting a nuclear plant underground.

5.6.2 Effects on Operational Costs

The design of an underground power plant must consider all of the same operation and maintenance requirements that apply to surface plants. Particular consideration should be given to any feature which could lengthen shutdown time during refueling or major maintenance. The safety and convenience of the operating and maintenance staff must always be considered since poor design could affect the plant's capacity factor.

The expedient completion of the refueling operation is a critical factor in the on-line availability of a nuclear power plant. The safety and logistics of this complex activity require the spent fuel storage facility to be located underground in close proximity to the containment chamber. Spent fuel casks will be used with plant in operation. A potential problem then arises with regard to the spent fuel cask. This massive and bulky cask must be transported into the underground facility by some means which will restrict the height from which it might fall in the event of gross equipment failure.

Another operational consideration in design of access passages to the underground sections of the plant is to assure the availability of reliable emergency evacuation systems for the operating staff. Complete sealing-off of the access ways is necessary in order to achieve total containment following an accident. All evacuation of personnel must be accomplished before ventilation systems and accessways can be closed off.

If the central control room is located underground, it should be designed so that it can be isolated from other chambers and provided with completely independent ventilation and access to the surface. This would allow continued habitation of the control center during subsequent emergency shutdown operations.

Maintenance of equipment is another area in which accessibility and the availability of adequate work space must be considered in the layout of the plant. The turbine hall is one major plant feature which must be substantially larger than equipment space requirements in order to provide laydown area for massive components during periodic maintenance.

During design of underground facilities there would be a tendency to minimize the volume and spans of the major plant features. This could lead to more compact arrangement of equipment which could, in turn, result in an undesirable increase in mechanical congestion. Sufficient space must be provided in equipment caverns to allow timely removal and replacement of frequent maintenance items. The repair or replacement of large contaminated system components would be particularly difficult in a limited access area.

5.7 Construction and Operational Cost Considerations

5.7.1 Effects on Costs

The economics of constructing an underground plant compared with a surface plant is a major factor when considering such an undertaking.

The economic penalties during the engineering, licensing and construction stages would include: 1) cost of excavation,

2) design modification to systems and equipment, and subsequent equipment revisions, 3) licensing acceptance, 4) extended schedule, and 5) increased labor costs.

The techniques used in mining of rock formations with a wide range of characteristics are well established. The primary concern in the application of this technology to underground siting is that the spans of the openings required for these facilities exceed the limits of past experience. Current technology is limited to spans of less than 30 m (100 ft.). Recent studies proposed several reconfigurations of existing reactor systems which would allow the maximum spans to be held to less than 30 m. This may well be a more appropriate approach to the design of mined rock cavity underground plants. The modifications suggested are basically of a geometric nature and the technical effort required to implement them would probably involve less uncertainty than the design of large span excavations.

Increased costs would include the circulating water system, ventilation facilities, access closure mechanisms, and construction equipment.

The physical size and mass of some of the reactor system components make their transportation through access shafts and tunnels a serious problem. This is further complicated by the fact that assembly on the surface for conventional nuclear power plants allows the partial prefabrication of subsystems in staging areas so that final assembly can be made with a minimum of interference with other construction activities.

If the design is such that equipment must be repaired in place, a considerable increase in downtime could result which would be borne as an economic penalty by the operating utility.

The total effect of the above noted operational constraints is expected to be a negative impact on plant availability, resulting in higher production costs than similar surface plant.

5.8 Conclusions

Although there are no technological barriers to a combination of UHPS and UNP it is doubtful, at best, that such an arrangement would be undertaken. Giving due recognition to the positive factors and gains such as reduced environmental conflicts, physical and public protection against man-made damaging influences, and plant accidents, the negative factors are considered to be overriding. These include costs, longer construction period, operational penalties, and potential impact on UHPS due to nuclear accidents.

There is no significant benefit to a tie-in of an underground nuclear plant and UHPS other than those stated above. The demonstration herein is to show how such a combination could be effected.

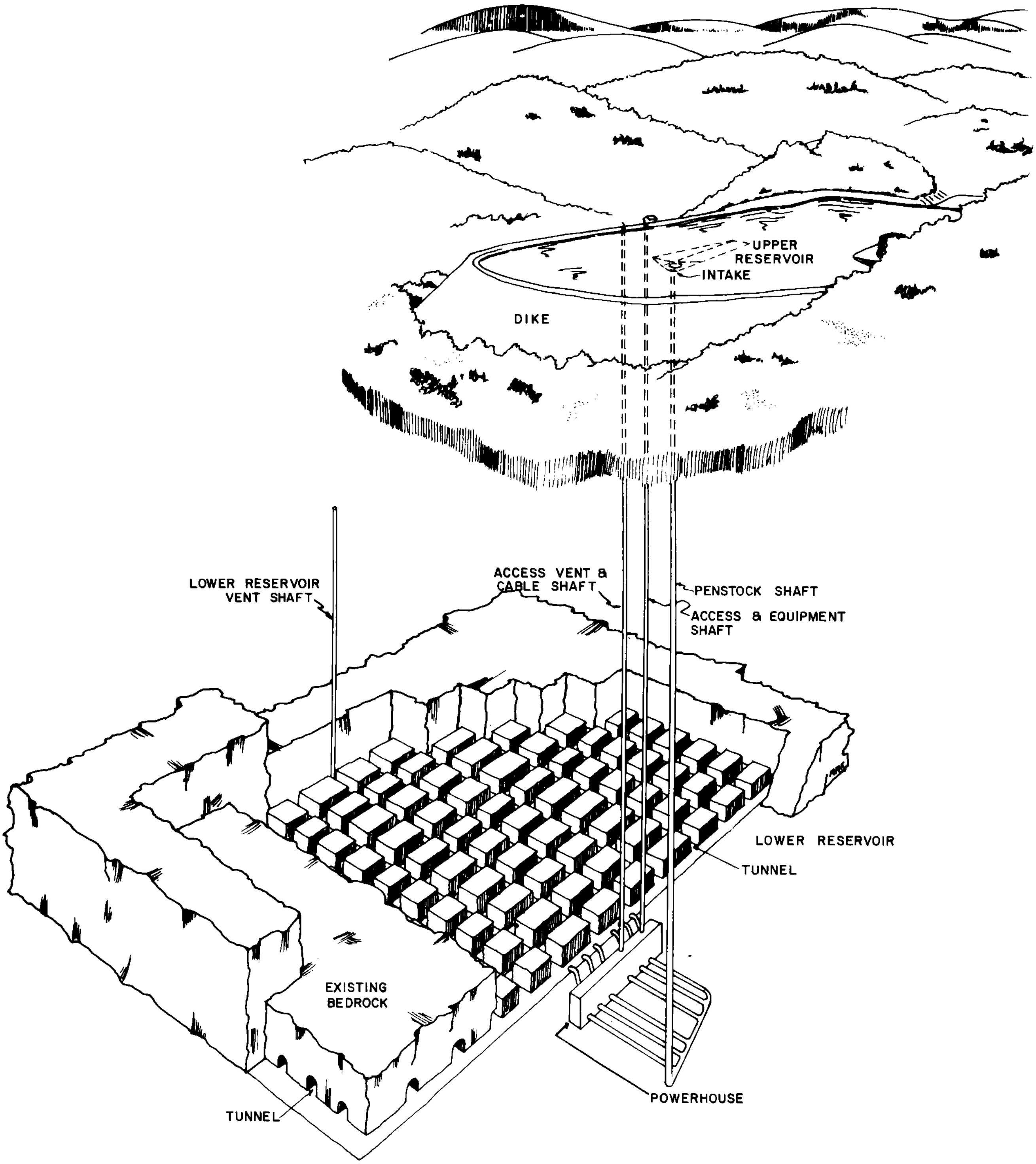
6.0 ENVIRONMENTAL AND SOCIAL EFFECTS OF UNDERGROUND HYDROELECTRIC PUMPED STORAGE

6.1 Introduction

The environmental effects most associated with UHPS, as described in previously published data, include disposal of excavated material, heat dispersal, water quality, and groundwater impact. These effects, in turn, can adversely impact or alter surface drainage, land use, terrestrial and aquatic habitat, and cultural, scenic and recreational resources of the area in which the project will be located. Project construction, although of relatively short duration, can also adversely impact an area. Consideration must be given to the accommodation of the construction work force and their demands on local services such as housing, hotels, motels and restaurants, schools, hospital, police and fire protection. Traffic noise and public safety are also important social concerns related to UHPS.

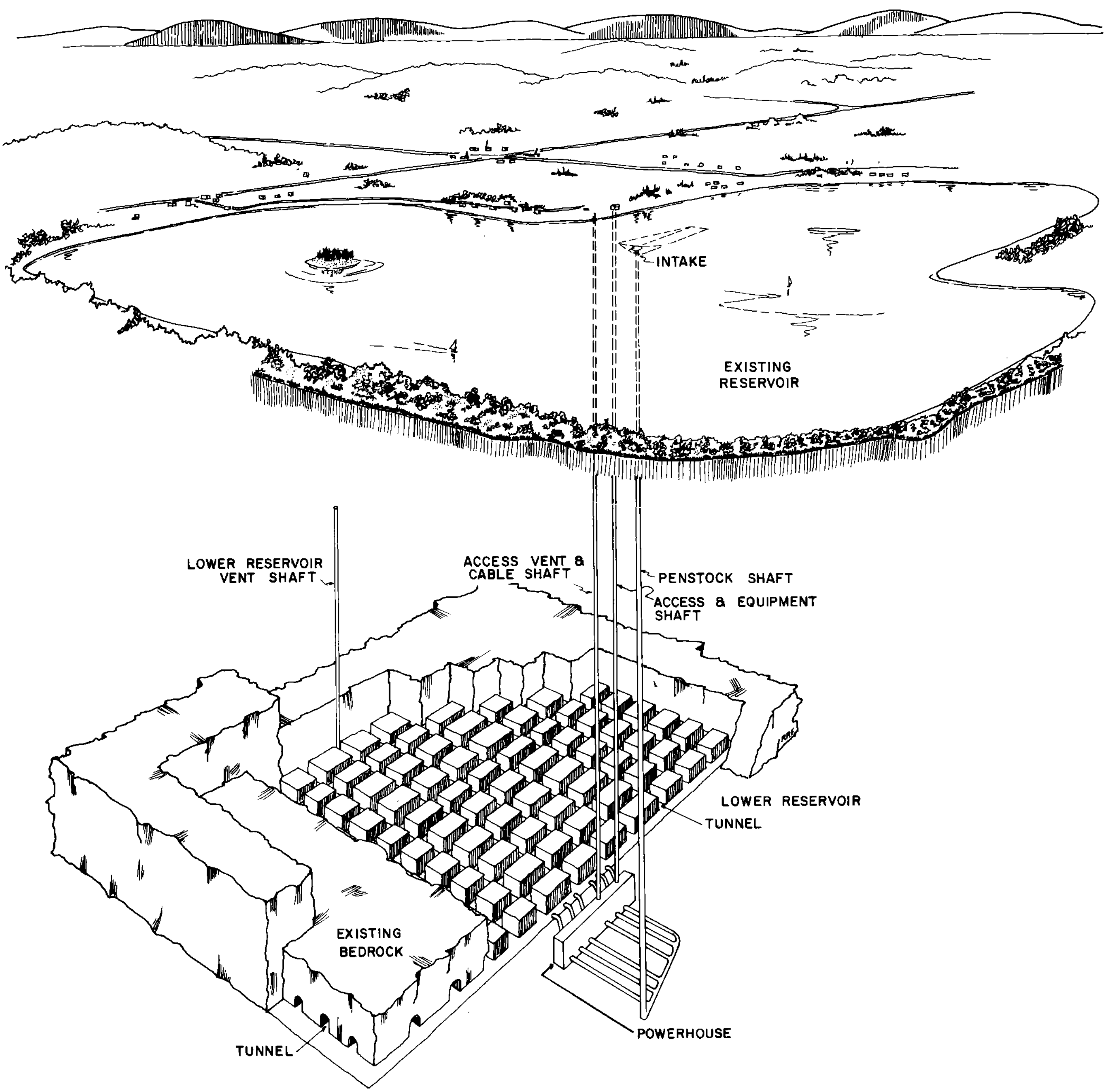
To assess the environmental effects most unique and significant to UHPS, four arrangements (see Plates VI.1 to VI.4) of a single stage 2000 MW plant with a 1200 m (4000 ft.) differential head and 10-hour generating capacity have been used as the basis of the environmental analysis. Cases 1 and 2 assume a man-made, excavated lower reservoir cavern, while Cases 2 and 4 utilize a natural cavern. Cases 1 and 3 have a man-made upper surface reservoir, while Cases 2 and 4 envision use of a natural or existing body of water. All four arrangements assume an excavated underground powerhouse chamber and similar waterway system.

6

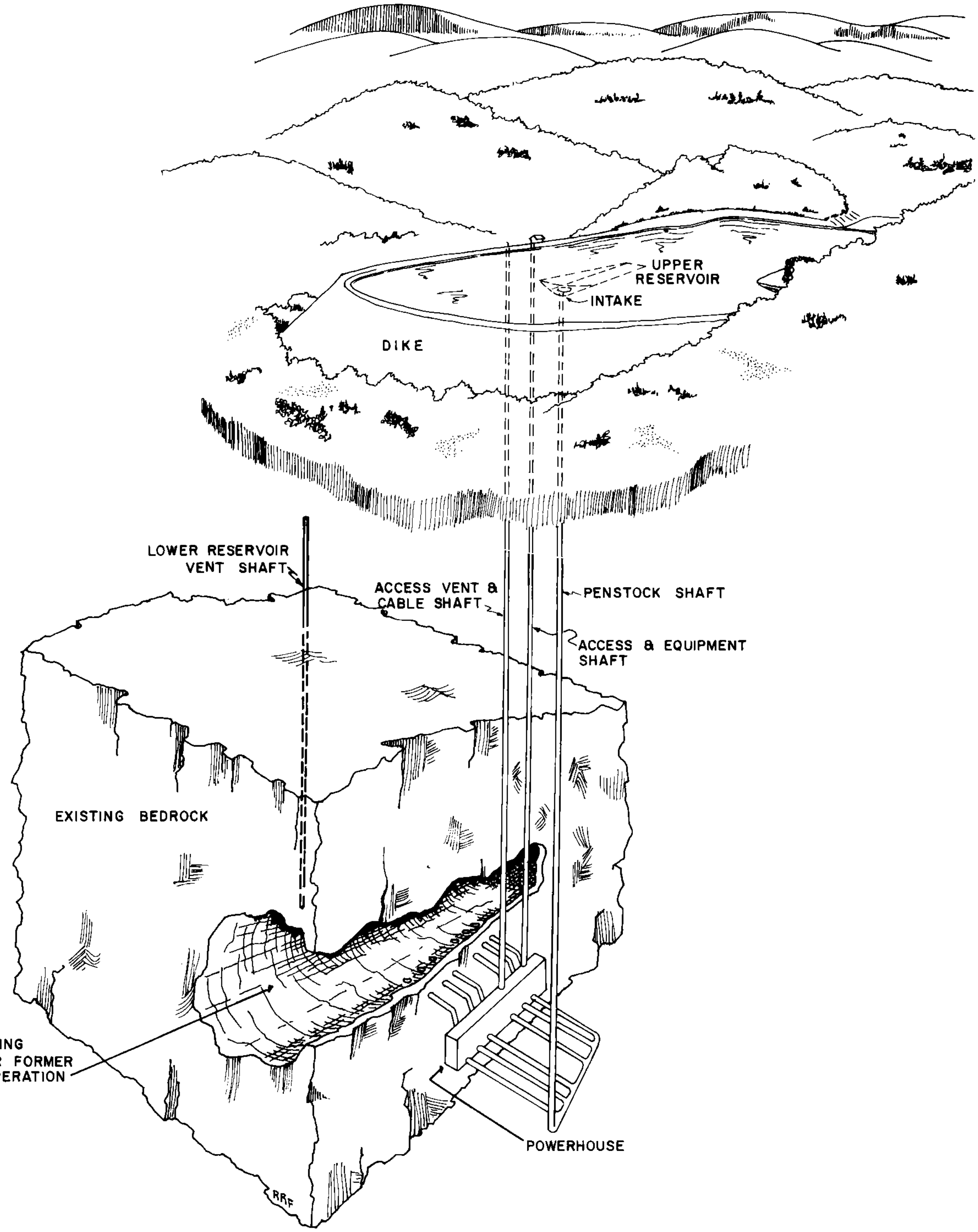


CASE I

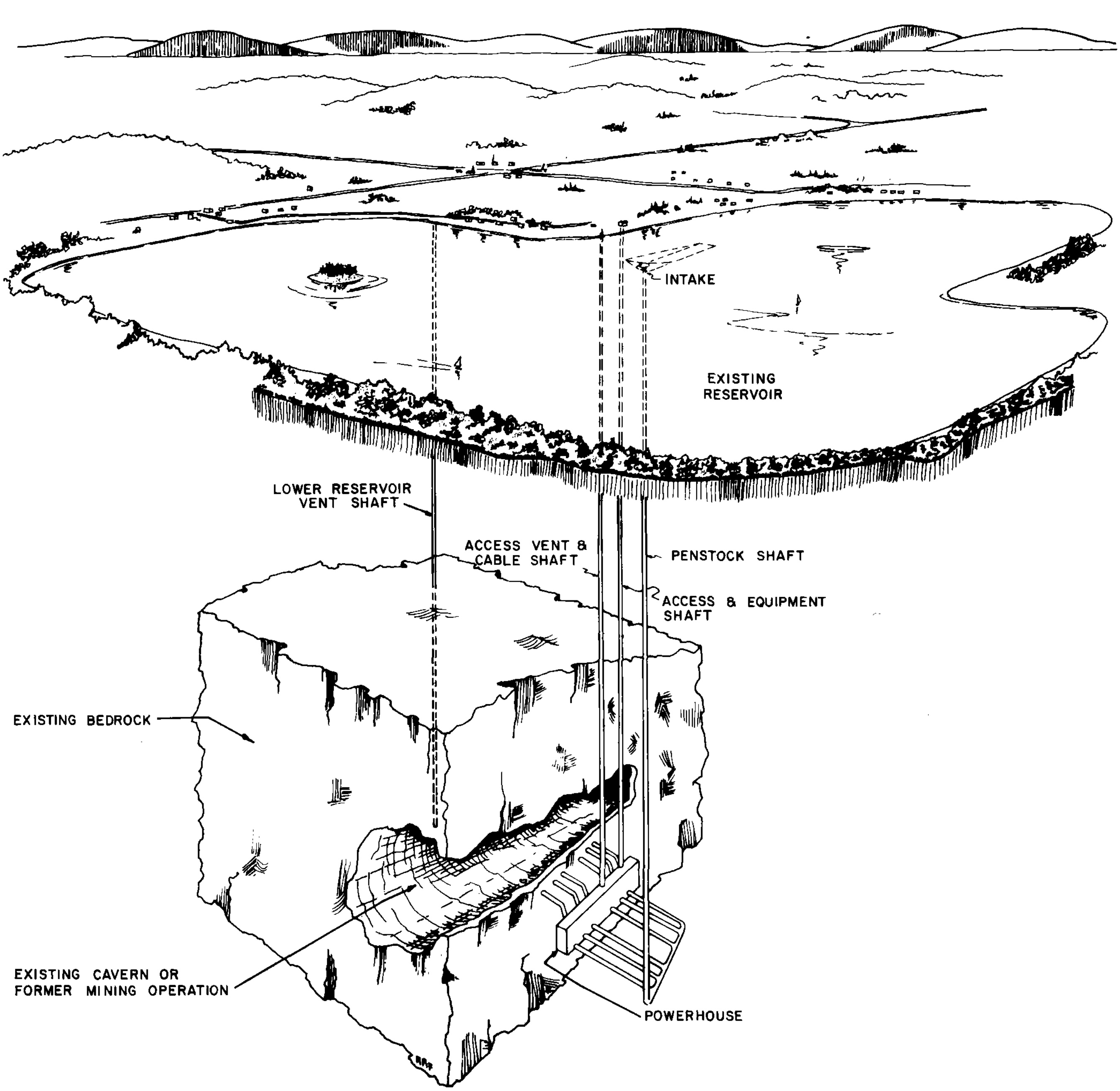
MAIN PLATE VI-1


INTAKE
EXISTING
RESERVOIR
LOWER RESERVOIR
VENT SHAFT
ACCESS VENT &
CABLE SHAFT
PENSTOCK SHAFT
ACCESS & EQUIPMENT
SHAFT
LOWER RESERVOIR
TUNNEL
EXISTING
BEDROCK
TUNNEL
POWERHOUSE

CASE II


UPPER RESERVOIR
INTAKE
DIKE
LOWER RESERVOIR VENT SHAFT
ACCESS VENT & CABLE SHAFT
PENSTOCK SHAFT
ACCESS & EQUIPMENT SHAFT
EXISTING BEDROCK
EXISTING CAVERN OR FORMER MINING OPERATION
POWERHOUSE
RRF

CASE III



INTAKE
EXISTING
RESERVOIR
LOWER RESERVOIR
VENT SHAFT
ACCESS VENT &
CABLE SHAFT
PENSTOCK SHAFT
ACCESS & EQUIPMENT
SHAFT
EXISTING BEDROCK
EXISTING CAVERN OR
FORMER MINING OPERATION
POWERHOUSE

CASE IV

Section 6.3 describes the technical, environmental and institutional considerations which must be considered in UHPS siting. Constraints will vary from site to site and from arrangement to arrangement. The expected environmental impacts and the measures which can be used to avoid or mitigate such impacts are discussed in Sections 6.4 and 6.5, respectively.

Section 6.6 addresses other generation modes which may be considered as alternatives to UHPS in the 2000 MW range. Those discussed include conventional hydro and pumped storage facilities, nuclear, fossil and internal combustion power. These represent the most commonly referred to and acceptable alternatives in license proceedings before the Federal Energy Regulatory Commission (FERC), a Commission which would license a UHPS project. The more exotic forms of energy generation, including solar and wind power, geothermal generation and small hydro power, are not considered as viable alternatives to UHPS because of the proposed generating capacity of the facility involved.

To place UHPS in a proper perspective with alternative forms of energy generation, a comparative evaluation of the significant environmental impact of each is set forth in Section 6.7. As summarized in Section 6.8, this comparison shows that a UHPS facility is a viable means of energy generation from an environmental point of view.

6.2 UHPS - Conceptual Arrangements

From an environmental point of view, site conditions can have a far more significant impact than will many of the important technical considerations. For example, the problems related to disposal of large volumes of excavated materials, and effects on surface and groundwater quality, may be more significant considerations than are such criteria as a single- or multi-drop reservoir system or a three- or four-unit station arrangement. To emphasize this point, four versions of a 2000 MW UHPS facility, each with a 10-hour generating capacity under a 1200 m (4000 ft.) differential head, have been selected for analysis to show important variances which may occur under varying site conditions.

The following is a description of each case for purposes of identification in this report:

Case	Concept	Plate
1	Man-Made Lower and Upper Reservoirs	VI-1
2	Man-Made Lower Reservoir with an Existing Upper Reservoir	VI-2
3	Natural "Cavity" Lower Reservoir with a Man-Made Reservoir	VI-3
4	Natural Cavern Lower Reservoir with an Existing Upper Reservoir	VI-4

These layouts are reasonable, typical arrangements for UHPS. The assumed criteria for each arrangement is presented in Table VI-1.

6.3 Siting Considerations

In the siting of large power generating facilities in the United States, planners are attempting to reach a delicate balance between system need and technical feasibility on the one hand, and environmental compatibility and overall cost on the other. If excessive cost is required to satisfy regulatory requirements or achieve compatibility between the project and its environment, then overall project costs can become non-competitive with other alternative means for meeting system needs. Conversely, the selection of a well-oriented site may save substantial project costs, minimize potential environmental impacts, reduce the time required for obtaining licensing and permit approvals, and time of construction. This section addresses potential environmental impacts that will influence UHPS siting.

6.3.1 Compatibility With Utility Systems

The only system siting constraints assumed for UHPS are those which would be self-imposed by a utility after consideration of all benefits to a particular system. Chapter 8 of this report addresses several synthetic utility systems which are broadly representative of regional electrical systems as they are expected to be structured in this country beyond 1985. The discussion in Chapter 8 is intended to serve as a basic guide for determining which system configuration would readily benefit from UHPS. Chapter 8 also discusses, generally, the break-even distances of high voltage transmission which UHPS could absorb and still remain competitive with alternative modes of generation.

TABLE VI-1

PROJECT DESCRIPTION - 2000 MW UNDERGROUND PUMPED STORAGE PROJECT

1200 m (4000 ft) Differential - 10-Hour Storage Capacity

Project Feature	Case I	Case II	Case III	Case IV
UPPER RESERVOIR				
Surface Area (Hectares) [2/]		150		150
Fluctuation - 10 m (32.8 ft)	72	NA	72	NA
- 20 m (65.6 ft)	36	NA	36	NA
- 30 m (98.4 ft)	24	NA	24	NA
Water Volume (Hectares - m)	715	715	715	715
* Dike Volume (Cubic Meters)				
Fluctuation - 10 m	874,000	NA	874,000	NA
- 20 m	1,980,000	NA	1,980,000	NA
- 30 m	3,815,000	NA	3,815,000	NA
Dike Length (Meters)				
Fluctuation - 10 m	3,090	NA	3,090	NA
- 20 m	2,260	NA	2,260	NA
- 30 m	2,140	NA	2,140	NA
Dike Base Area (Hectares)				
Fluctuation - 10 m	13	NA	13	NA
- 20 m	53	NA	53	NA
- 30 m	23	NA	23	NA
Surface and Dike Area Required(Hectares)		150		
Fluctuation - 10 m	85	NA	85	-----
- 20 m	53	NA	53	-----
- 30 m	47	NA	47	-----
CONSTRUCTION AREA				
Surface Area Required (Hectares)	40	40	40	40
STATION FACILITIES				
Surface Area Required (Hectares)	2-4	2-4	2-4	2-4
[1]TOTAL LAND REQUIRED (Hectares)				
Fluctuation - 10 m	127-129	192-194	127-129	192-194
- 20 m	95-97		95-97	
- 30 m	89-91		89-91	

* Minimum Dike Slope - Inside 1.7 to 1; Outside 1.5 to 1
Upper Reservoir

CHAS. T. MAIN, INC.

TABLE VI-1 (Cont.)

	Case I	Case II	Case III	Case IV
LOWER RESERVOIR				
Storage				
Required Active Storage (Cu. M)	7,200,000	7,200,000	* 3/	* 3/
Required Dead Storage (Cu M)	222,000	222,000	*	*
WATERWAYS				
Volume (Cubic Meters)				
Power Shaft	1,250	1,250	1,250	1,250
Penstock	1,150	1,150	1,150	1,150
Draft Tubes	500	500	500	500
Manifold	200	200	200	200
Vent Shaft	1,250	1,250	1,250	1,250
Construction Adits	400	400	400	400
Sub-Total	4,750	4,750	4,750	4,750
POWERHOUSE				
Volume (Cubic Meters)				
Access Shaft	1,250	1,250	1,250	1,250
Cable Shaft	1,300	1,300	1,300	1,300
Powerhouse	150,000	150,000	150,000	150,000
Sub-Total	152,550	152,550	152,550	152,550

NOTE:

1/ Required areas for access roads, transmission rights-of-way, areas developed for public use, or on- or off-site disposal areas have not been included because of variability.

2/ Recommended Minimum Area required for natural reservoirs. Low fluctuations are employed thereby preventing major environmental impacts.

3/ * An appropriate cavern equal to Case No. 1 is required. Partial excavation may be required.

6.3.2 Technical Requirements

The quantity and quality of subsurface rock, available water and suitable surface terrain are all essential UHPS siting considerations. Other important technical factors include the availability of suitable areas for spoiling, existing transportation facilities, and transmission corridors, adequate space for temporary contractor work areas, and long-term maintenance areas. As shown in Table VI-1, the requirements will vary from arrangement to arrangement. They will also vary from site to site according to specific site conditions and ultimate development needs. This section discusses some of the significant technical criteria influencing the site selection process.

a. Land Requirements

The land requirements of a UHPS facility (Table VI-1) vary and depend on site-specific conditions, facility size, and appurtenant works required. Under Cases 1 and 3, the upper reservoir, including dikes, will range from 47 ha. (116 ± acres) for a 30 M. (98 ± ft.) drawdown to 85 ha. (210 ± acres) for a 10 M (33 ± ft.) drawdown. Additional space is required for construction and operation areas, disposal areas and for related appurtenant works, including transmission and transportation facilities. Construction work areas will vary in size but an allowance of 40 ha. (100 ± acres) is deemed reasonable for a 2000 MW facility. (Assuming a 15 M. (49 ± ft.) high disposal pile with 15 percent bulking and one on two side slopes, the size would range from 1 ± ha (3 ± acres) for Case 4 up to 51 ± ha (126 ± acres) for Case 2.) Additional allowance must be made for access roads. With respect to transmission, an allowance must be made for switchyard or substation facilities, or both, and for the transmission corridor. Station facilities will require in the order of 2 ± to 4 ± ha. (4 ± to 10 ± acres) while a transmission right-of-way will vary in width from 91 ± to 122 ± M. (300 to 400 ft.) This equates to 15 ± to 20 ± ha. (36 to 48 ± acres) per mile. Additional space should be considered and may be required to provide scenic, wildlife and public recreational benefits from project development. The acquisition of such property for mitigative purposes is accepted, within reason, by the FERC as part of the overall project cost. Further additional space may be required by the developing utility to satisfy project operation, maintenance and control objectives. All long-range needs, such as proposed land development and recreational areas, should be identified and considered in the initial siting process.

b. Disposal of Excavated Material

Table VI-1 presents the quantities of excavated materials which can be expected under the four UPS arrangements. Surplus material will range from 157,000 M^3 (205,000 cu yd) for Case 4, to 7,559,000 M^3 (9,887,000 cu yd) for Case 2. This material must be disposed of either on or off-site in a manner acceptable to Federal, State, Regional or Local rules and regulations. Consideration should also be given to secondary use of excavated material, whether on or off-site. On-site use of this material may range from the construction of offshore islands, roads, operation and maintenance areas to the construction of make-up water storage areas or water pollution control settling basins. Off-site use should consider public and private sale for re-use or for the construction of community facilities.

c. Borrow

While the availability of suitable borrow is an important consideration in the selection of conventional hydro and pumped storage sites, it is not significant to UHPS except for Case 3 where a suitable natural underground cavern is assumed for the lower reservoir and utilizing a man-made upper reservoir. In this instance, 1,823,000 M^3 (2,384,000 cu yd) of suitable borrow material would be required for the construction of the upper reservoir dike. Under the other arrangements, the amount of borrow required would depend on the suitability of excavated materials to serve construction needs.

d. Water

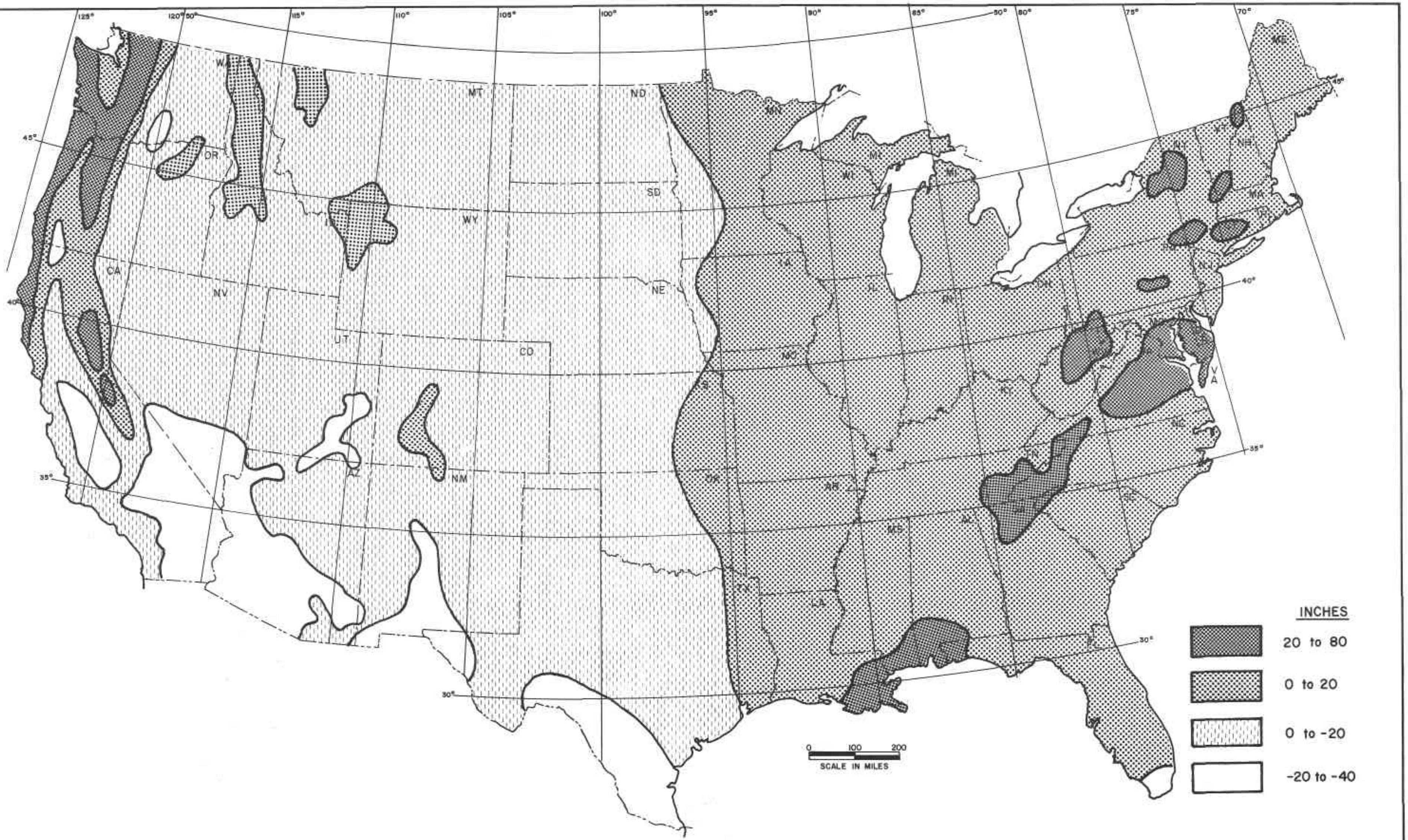
The availability of a water supply is essential to the siting of UHPS. A 2000 MW facility will require 7,155,000 M^3 (5,800 acre-ft) of water for initial fill-up and in the range of 62,000 M^3 to 740,000 M^3 (50 to 600 acre-ft) annually for make-up, depending on the evapotranspiration characteristics of the site under consideration. Assuming a 50-year project life, the maximum duration of a FERC license, make-up water will range up to five times that required for initial operation. From a technical point of view, any site having this amount of water available with suitable geology is a potential UHPS site. This is not necessarily true environmentally. The environmental impact on water is not measured in terms of quantity used, but rather in terms of overall effect on existing water supplies, whether on the surface or in the ground. The pollution of each could have far-reaching effects that could disqualify a site unsuitable if control is found unfeasible from either an institutional, technical or economic standpoint.

The impact on water, however, is a factor which all major systems of generation must contend with. In this, UHPS appears to have an advantage over other generation systems. The four UHPS arrangements discussed earlier in this chapter assume either a man-made or natural lower reservoir cavern and utilization of either a man-made or existing upper reservoir. These alternate arrangements, above and beyond those technical arrangements discussed in Chapter 4, allow a siting flexibility that can eliminate many adverse effects on water quality. For example, assuming a water source is available, a man-made dedicated upper reservoir, with no off-site discharges, would eliminate degradation of off-site water quality, one of the major siting problems facing the power industry today. This would also maximize the use of natural underground caverns if the plant need not be located immediately adjacent to an existing stream or body of water under stringent regulatory control. In this instance, the cost savings of using natural caverns should be weighed against the cost of developing a water supply, whether diversion of a surface water supply, use of a groundwater supply, or the tapping of a subterranean source. Even in the use of an existing and suitable surface supply, siting flexibility is gained by the minimal surface needs of UHPS, apart from the spoiling of excavated material. A discussion of more significant environmental and institutional constraints relating to water quality follows.

The hydrologic characteristics of the United States are contained on Plates 6.5 through 6-9. (U.S. Water Council - 1968)

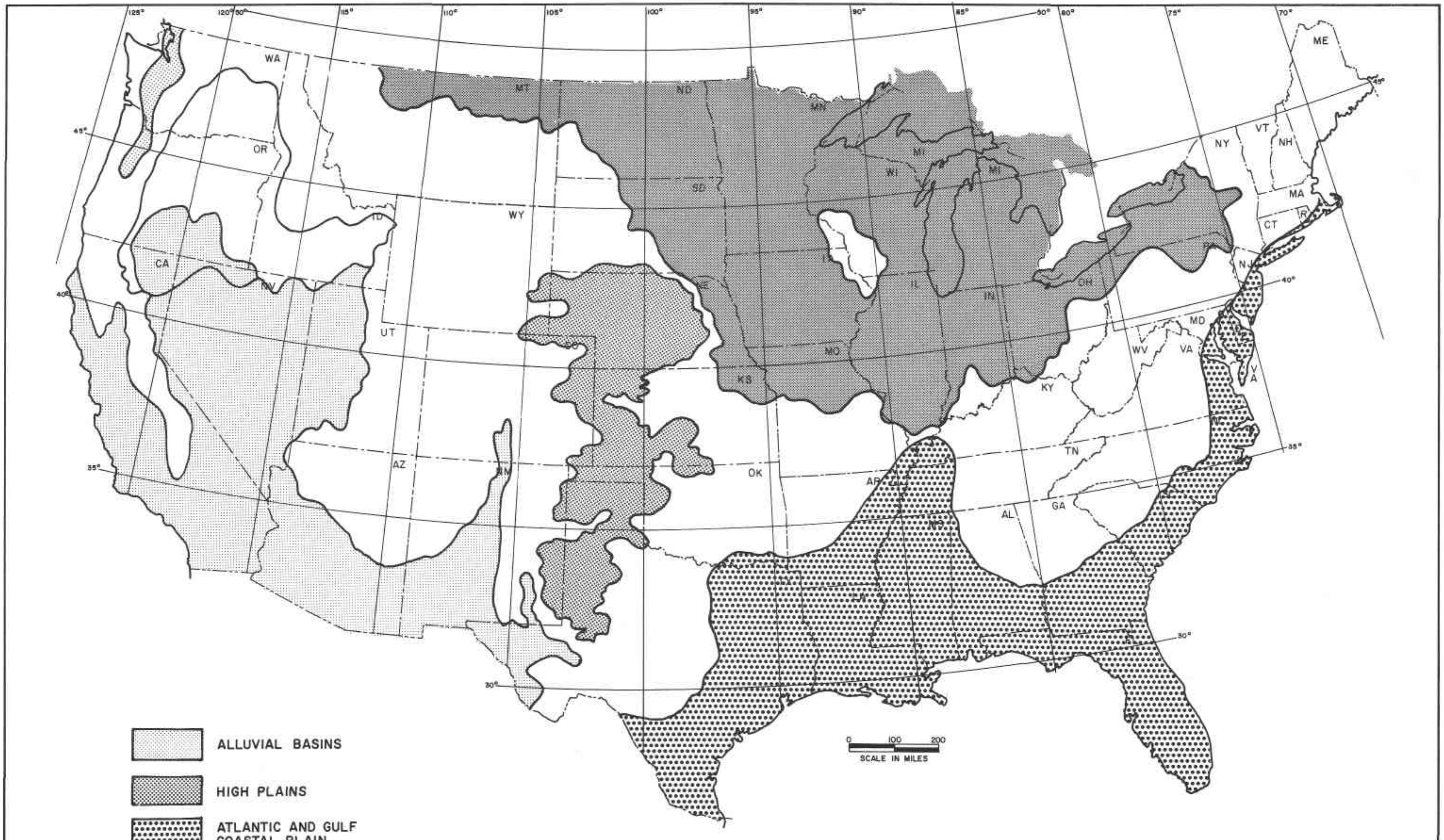
6.3.3 Environmental - General

Every potential UHPS site will have its own unique environmental characteristics which may be more or



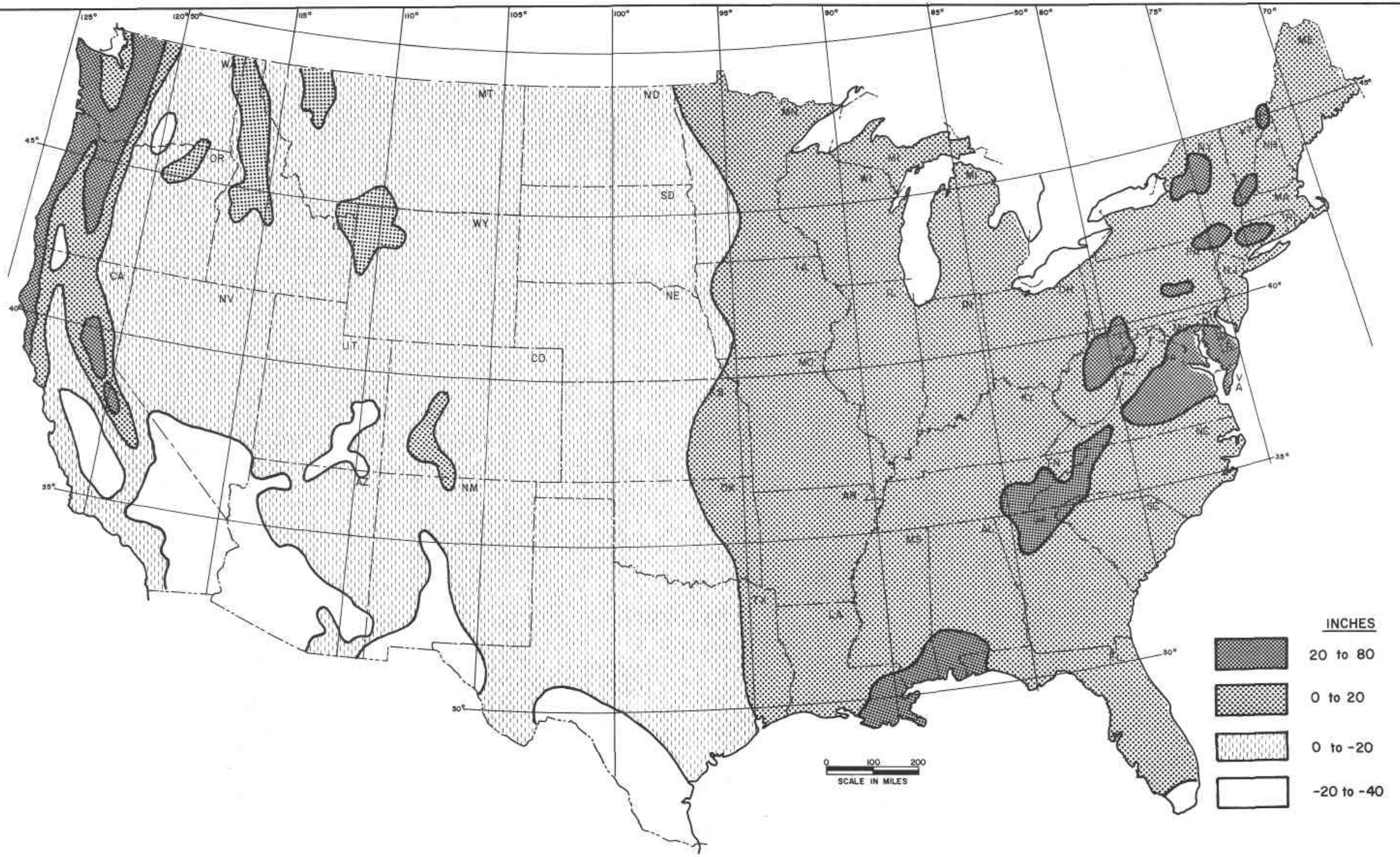
AREAS OF NATURAL WATER SURPLUS AND NATURAL WATER DEFICIENCY

MAIN PLATE VI-5



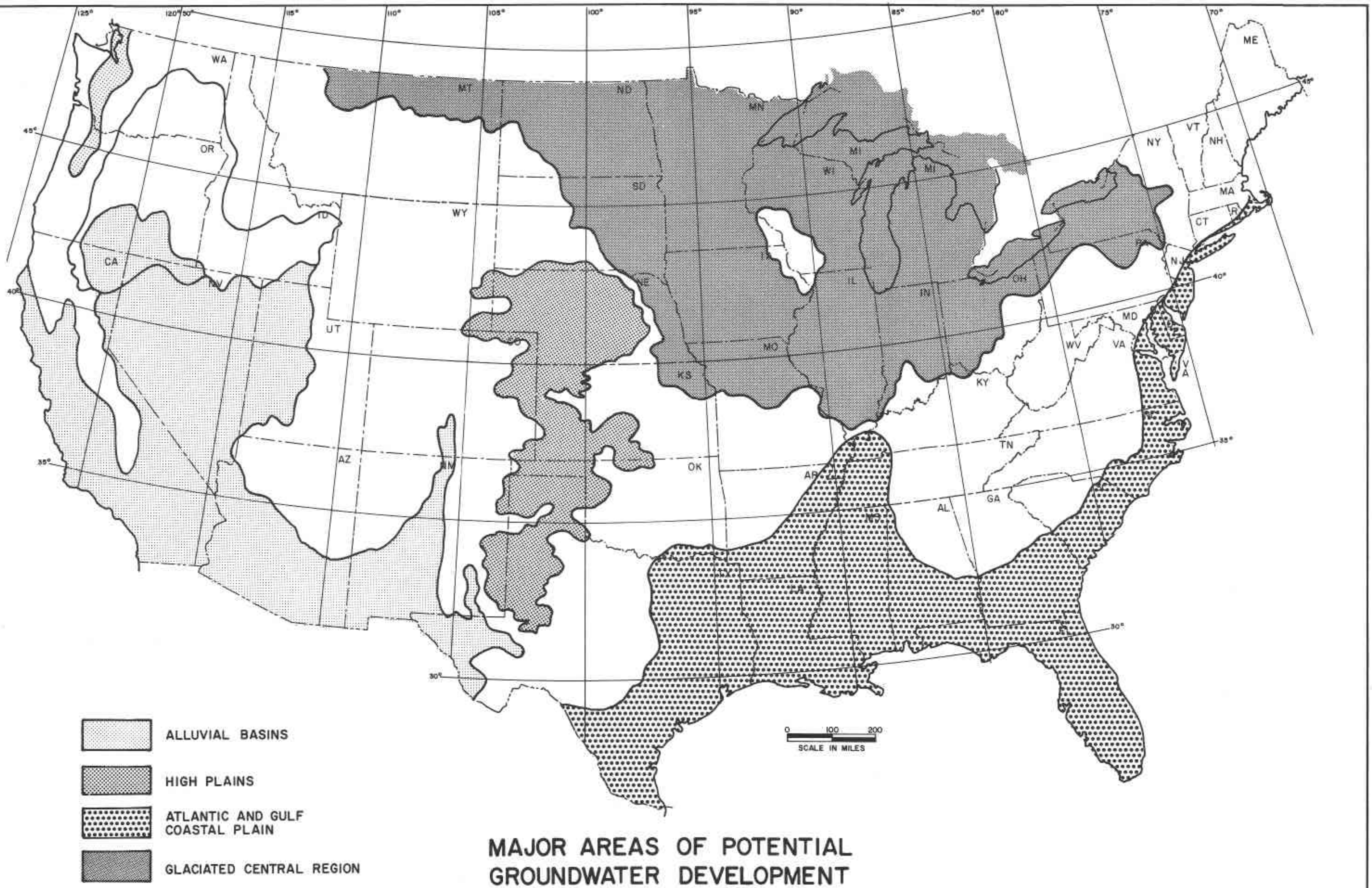
MAJOR AREAS OF POTENTIAL GROUNDWATER DEVELOPMENT

MAIN PLATE VI-6

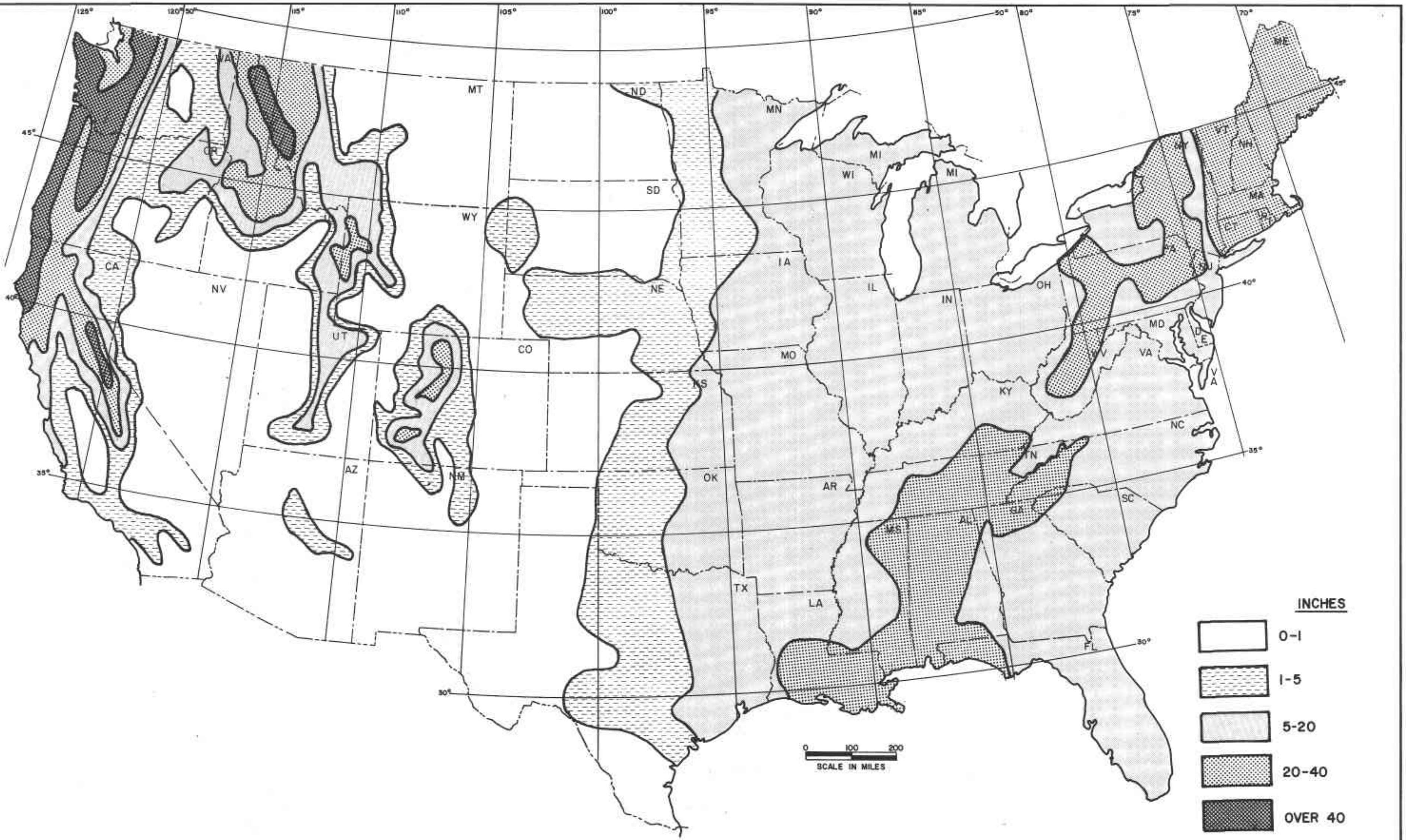


AREAS OF NATURAL WATER SURPLUS AND NATURAL WATER DEFICIENCY

MAIN PLATE VI-5

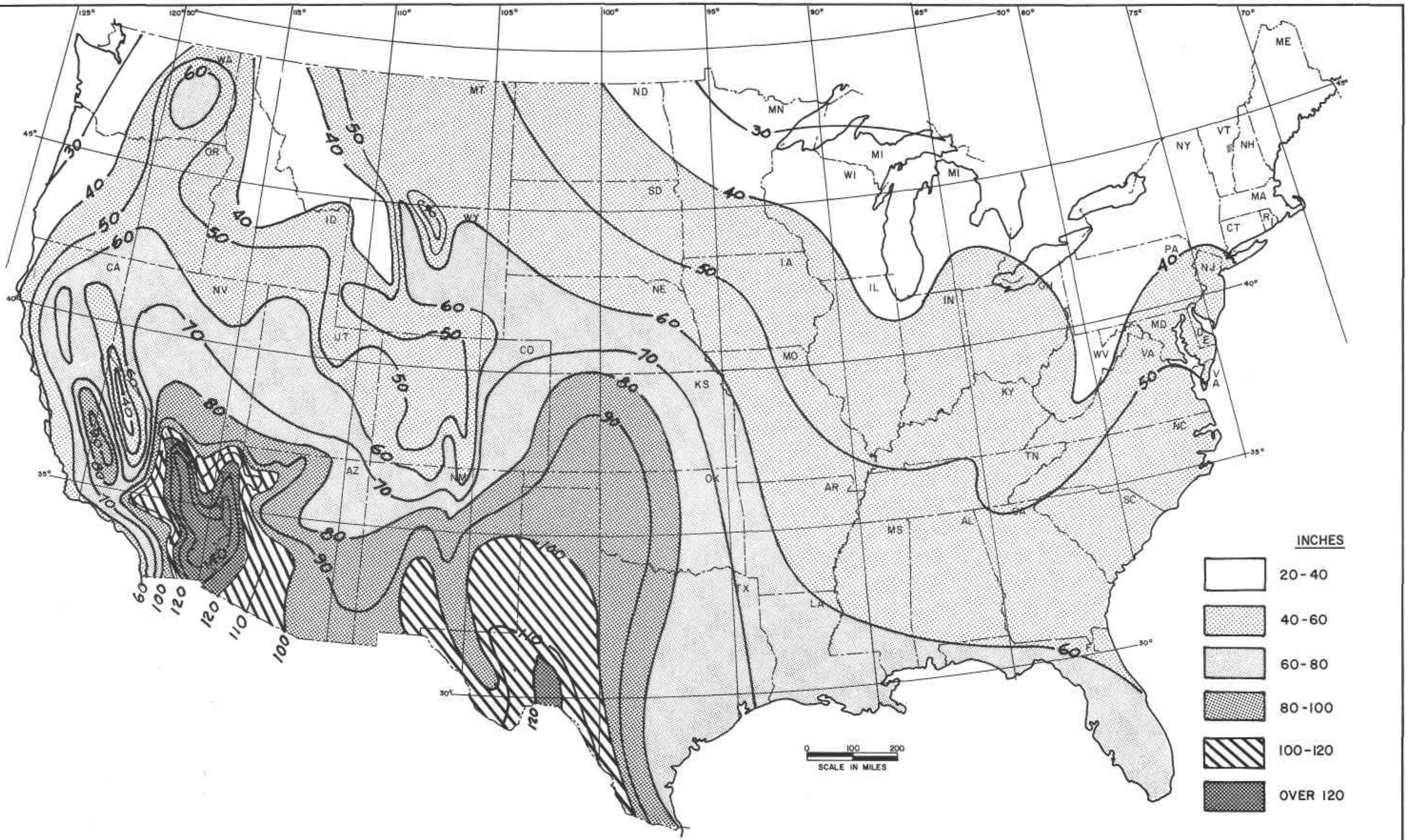


MAJOR AREAS OF POTENTIAL
GROUNDWATER DEVELOPMENT



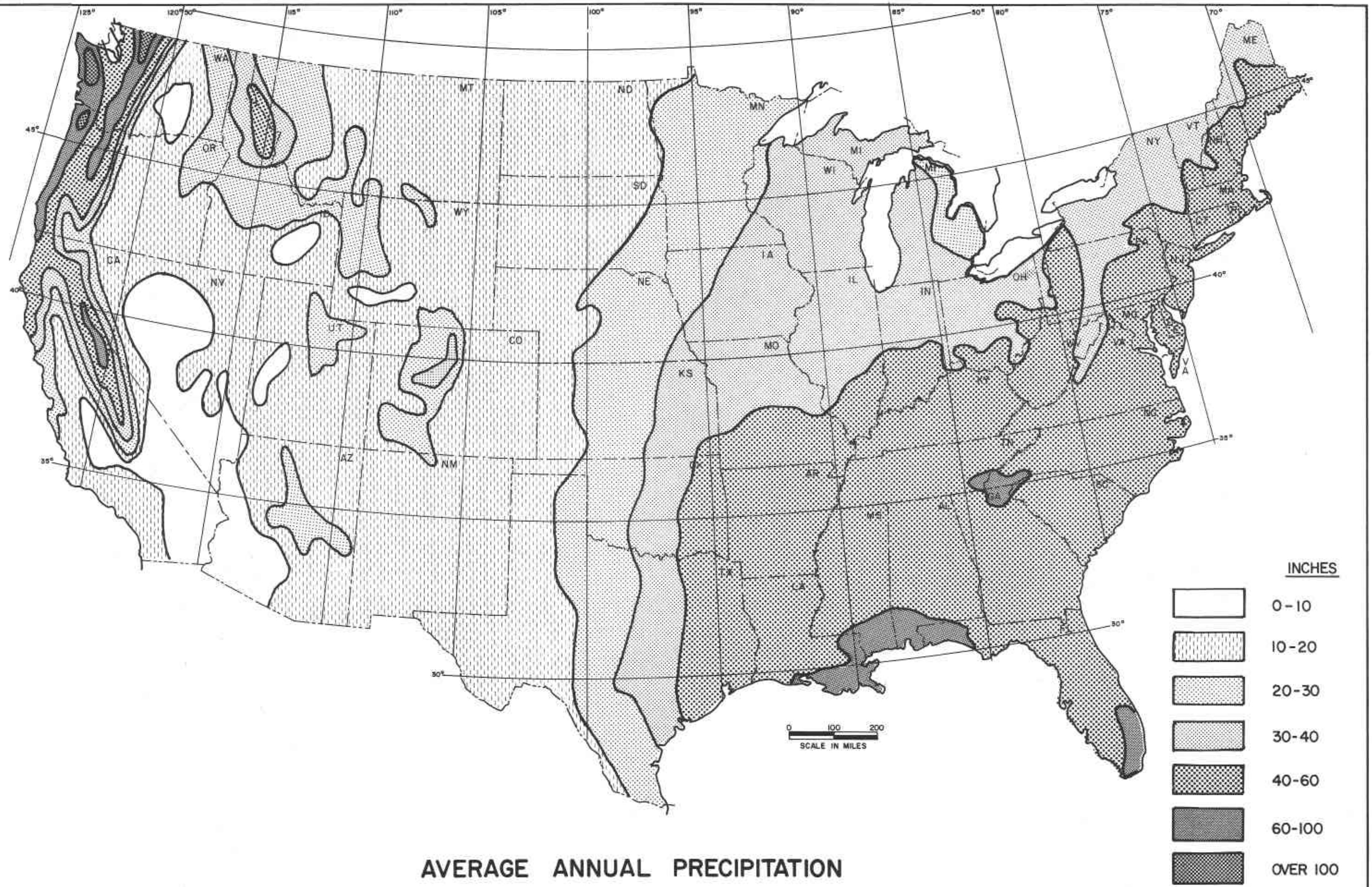
AVERAGE ANNUAL RUNOFF

(MAIN) PLATE VI-7



AVERAGE ANNUAL PAN EVAPORATION

MAIN PLATE VI-8



AVERAGE ANNUAL PRECIPITATION

MAIN PLATE VI-9

less sensitive to project construction and operation. These characteristics may be bio-physical or socio-economic and represent varying degrees of impact and potential mitigation. The objective of site selection is to anticipate the degree of potential impact and to avoid or minimize adverse effects wherever possible. Environmental suitability will ultimately depend on the priorities and goals of the planning entity and will necessarily be a balance between objective and subjective considerations.

6.3.4 Environmental Variables

The following environmental variables are representative of those factors to be considered in the siting of a UHPS project. These factors will, of necessity, vary with the project configuration and project-specific priorities. Possible sources of information are suggested as an aid in the identification and evaluation of environmentally sensitive variables. Environmental impacts relative to these and other variables are discussed in Section 6.4.

a. Land Use

Priorities regarding the availability of existing proposed land use must be established for potential siting. Areas, such as State or National Parks, areas of high economic productivity, urban areas, and other dedicated areas are generally regarded as areas that should be avoided, although their availability may be considered if well-suited for UHPS. Low quality forest land, pasture, inactive strip mining areas, and other such lands generally represent areas with few constraints. Planned development, future land use trends, and commitments such as water and mineral rights, must also be evaluated. Federal, State and local planning maps, area development objectives, and land use guidelines provide basic data for the siting process.

b. Unique Biota

Areas inhabited by rare or endangered species of plants or wildlife must be identified. Ecological conditions which provide a critical link in the life cycles of these species must also be considered. This includes unique habitat critical to the propagation and existence of a species, although that habitat may not be continuously utilized; e.g., spawning areas, migration routes, wintering areas. Critical elements or species in the food chain must not be overlooked and the habitat of that secondary species identified. The effect of project water quality on downstream aquatic flora and fauna must also be considered during the siting process. Federal, State and regional agencies involved in wildlife management and conservation prove to be an invaluable source of information. State universities, private conservation groups and local residents are a source of detailed information on local conditions.

6

c. Physiography

Although the concept of UHPS eliminates the strict topographic requirements of the conventional pumped storage configuration, the modification of existing land forms for the construction of the surface reservoir is an environmental factor to be considered. Areas of a topographic character which comprise part of a critical watershed, maintain unique groundwater conditions, or support a unique or fragile ecology, may be considered areas of constraint. Soils highly susceptible to erosion, slumping, or other conditions must be identified as a potential source of impact to water quality as turbidity, sedimentation, or increased water nutrient levels. Slopes, soil stability, and soil composition are important factors during the planning of project road requirements for construction and transmission.

The U.S. Soil Conservation Service, State agricultural extension agencies, universities, and local geologists and soil scientists may provide data concerning critical watersheds, groundwater, soil characteristics, etc.

d. Disposal of Excavated Material

Disposal of the large volumes of excavated material from alternative construction schemes requires relatively large areas of land, either on- or off-site. Areas of low priority land use provide the most logical disposal areas, but must be located at a distance which proves econonically and environmentally acceptable. Impacts associated with the transport of the material include degradation of the existing road systems, potential social impact of traffic congestion, and emission of hydrocarbons from internal combustion engines. Under Case 2, for example, where transport of approximately 600,000 loads of spoil would be required, distance to the disposal site may represent a factor of considerable economic importance.

If it is anticipated that the chemical composition or stability of the spoil requires special disposal procedures, special attention must be given to depth to water table, soil characteristics, lining of the disposal area, and appropriate drainage techniques.

The regulatory requirements associated with disposal operations are discussed in Section 6.3.4. Federal agencies, such as the Environmental Protection Agency and the U. S. Army Corps of Engineers, and State agencies governing disposal of materials and land fill operations, should be involved in the initial siting process concerning physical and environmental requirements, as well as regulatory guidelines involved. Particular emphasis should be placed on Section 404 requirements under the Federal Water Pollution Control Act.

e. Accessibility

An additional factor to be considered in the siting of a UHPS system is the availability of existing transportation systems and the difficulty of developing access to an area in an environmentally acceptable manner. Topographic and soil conditions must permit the construction of roads to meet the requirements for access by equipment of the size and weight required for such a project. The volume of traffic, especially if off-site disposal of excavated materials is required, must be anticipated in access road construction consideration.

f. Recreation, Historic, Archaeologic and Scenic Areas

Areas of unique social or cultural interest must be identified. The potential impact of the project upon these areas must include not only possible physical encroachment on the area and the resultant impacts, but non-tangible impacts such as visual impacts and noise pollution. These factors must be considered in both the short-term and long-term frame of reference and a corresponding importance or sensitivity assigned for comparative evaluation.

Nationally-recognized historic sites are documented in The National Register of Historic Places. State Historic Preservation Offices maintain information on State historic sites and inventories of public and private recreation facilities. State universities and museums provide information concerning sites of archaeological significance. Many local or county planning commissions have, with Federal funding, published information concerning local scenic and historic sites and areas.

g. Utility Corridors

These linear variables include existing as well as planned transmission corridors, transportation rights-of-way, pipeline rights-of-way, etc. They may represent constraining factors; e.g., the potential displacement of a highway by the surface reservoir, or positive factors; e.g., the possibility for the required transmission facility to share an existing utility corridor, thus minimizing overall transmission impacts.

Location, size and information concerning the feasibility of joint corridor use can be sought directly from electrical, telephone and gas companies, as well as regulatory State agencies; e.g., public utilities commissions and regional power pools.

6.3.5 Socio-Economic Considerations

The maintenance of the work force (and their families) required during project construction and operation requires an adequate social and physical infrastructure in communities within commuting distance of the project. If the number of communities is limited, the existing facilities; e.g., schools, hospitals, police force, fire protection, commercial establishments, and available housing, may not be adequate to meet the needs of a large, long-term work force. Therefore, community and areal capacity to support the projected influx of people must be anticipated. Inadequate support facilities may well result in unanticipated loss of work time and delay in project schedules.

Accurate estimates of the total work force by duration of employment must be available to approximate the number of families expected to become established in the community. The capacity of local hospitals and schools should be investigated. Consultation with local fire and police administrators will provide information concerning overall capabilities of those services. Other relevant offices or agencies concerned with social services; e.g., Chamber of Commerce and housing administration, can also provide indications of a community's capability to cope with an influx of population.

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6.3.6 Institutional

We may assume that any proposed UHPS facility would be subject to a U. S. Department of Energy, Federal Energy Regulatory Commission license under the Federal Power Act, as well as conditions imposed by Federal and State permits and regulations. Under this assumption, a utility would have to prepare a full license application for a new major project, including an Exhibit W and related exhibits, as well as Federal, State and local permits. This would require that the following broad environmental categories be addressed:

1. Description of the proposed action;

2. Description of the existing environment;

3. Environmental impact of the proposed action;

4. Measures advanced by the applicant to enhance the environment or to avoid or mitigate adverse environmental effects;

5. Unavoidable adverse environmental effects;

6. Relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity;

7. Irreversible and irretrievable commitments of resources;

8. Need for project power and alternatives to the proposed action;

9. Permits and compliance with other regulations and codes;

10. Sources of information.

It should be pointed out that these cited categories are consistent with the Council of Environmental Quality guidelines under the National Environmental Policy Act. On a new, major project these categories require extensive effort, addressing both short and long-term, direct and indirect impacts. Short term impacts and benefits are assumed to occur during construction. Long-term impacts are assumed to occur through the life of the project and long after the initial 50-year license period. Direct impacts relate to the environment actually affected by project development, such as changes in land use, removal of vegetation, wildlife and aquatic habitat, changes in water and air quality, noise, effects on human and cultural quality and resources, as well as traffic and socio-economic impact, etc. Indirect impacts involve such items as visual quality of adjacent areas, effects on regional development patterns and community services.

Although existing published and unpublished data may be used to great advantage in describing the environment, air and water quality, terrestrial and aquatic baseline studies may take a year or more to complete. Normally, at least one full year of data is required. Once the environmental impacts, beneficial or adverse, of the proposed projects are defined, the applicant must cite those measures that will be taken to mitigate or avoid adverse environmental effects. These measures can be in the nature of facility design, construction procedures and operation or maintenance techniques which will mitigate or avoid direct adverse impacts. With regard to indirect impacts, recreation, aquatic, wildlife or community betterment type of programs may suffice. If adverse environmental effects cannot be mitigated or avoided, then these impacts must be cited as unavoidable and must be weighed against project benefits.

The need and justification for project power are essential parts of the analysis but may be considered a non-environmental issue. However, alternatives for meeting the need most certainly are, and must be, addressed. The alternatives range from discussions of various underground pumped storage sites, different site arrangements, other modes of generation or means of supplying power, or no action.

Finally, a complete environmental impact assessment must include consultations and input from all interested governmental agencies and interested parties. This input, early in the project planning stage, can speed up the overall license review process.

Regulatory legislation and laws governing site selection of power plants and transmission facilities are becoming more prevalent due to an environmentally conscious public. Important Federal laws that must be addressed in the initial phase of project development include the National Environmental Policy Act, regulations administered by the Federal Energy Regulation Commission (FERC) and the U. S. Corps of Engineers, Sec. 404. Other important Federal environmental regulations include the Federal Water Pollution Control Act, the Clean Water Act of 1977, the Clean Air Act, and the Solid Waste Disposal Act.

State regulations governing siting have increased considerably in the last few years with states having site-selective laws. State legislatures have become keenly attuned to the environment, requiring utilities to conduct in-depth studies as to potential and specific impacts to the environment. It is expected that, by the mid 1980's, all states will have in-depth rules and regulations governing the siting of electric power generating facilities. Therefore, public and private utilities must negotiate with State, regional and local authorities to attain swift confirmation of a proposed site.

6.4 Significant Environmental Impacts Applicable to UHPS

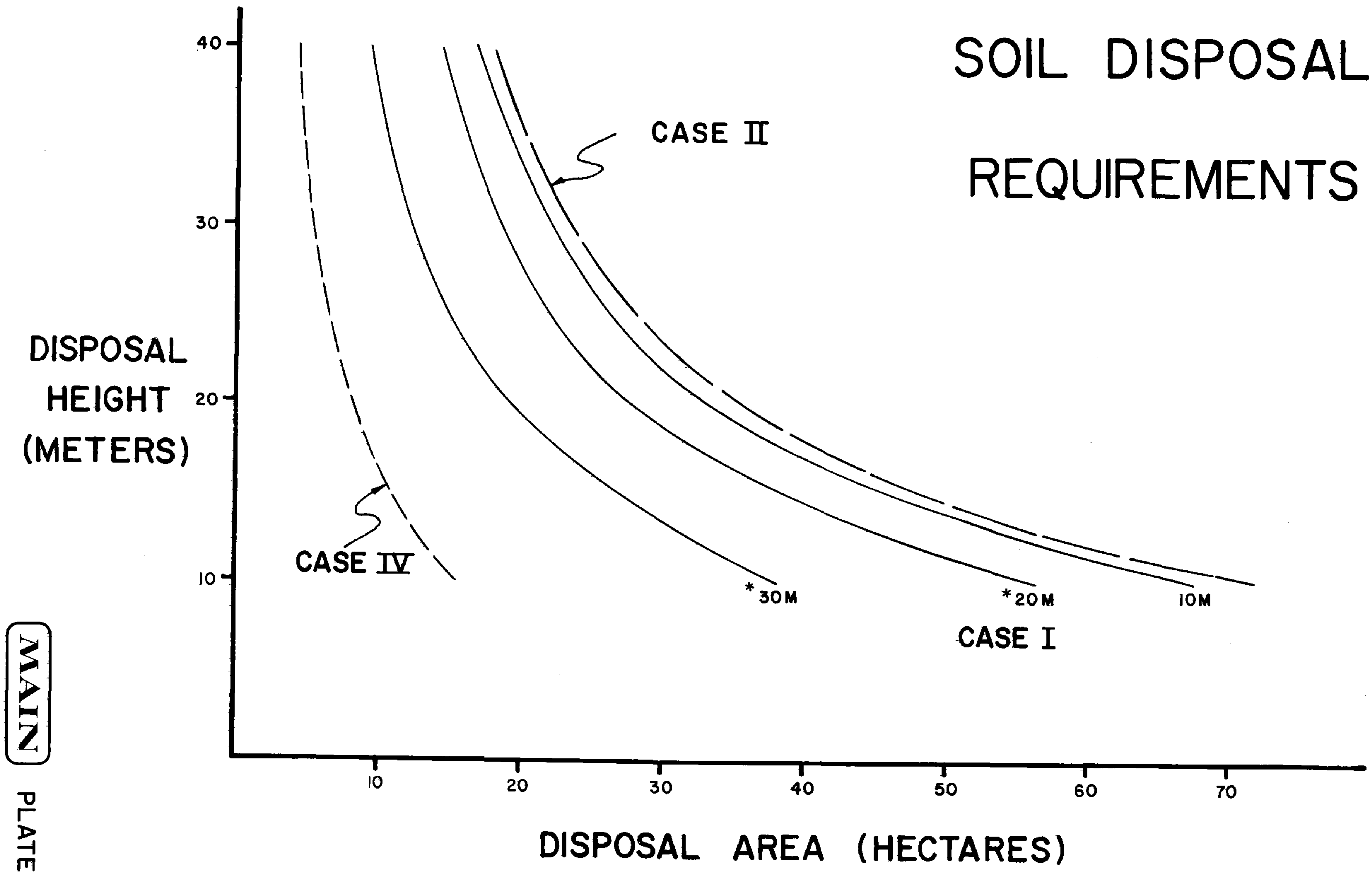
Significant environmental impacts attributable to UHPS and those which would most likely occur regardless of project size and location, or when the project is built, are summarized in this section. The measures which may be considered to eliminate or alleviate such impacts are discussed in Section 6.5.

6.4.1 Disposal of Excavated Material

A major impact associated with a UHPS project will be the disposal of substantial amounts of excavated material in all configurations requiring excavation of an underground reservoir cavern. As indicated in Table 6-1, between 5,442,000 and 7,442,000 cubic meters of material will be excavated for either on-site or off-site disposal. This would represent an area of 60 hectares (150 acres) of land covered to a depth of 9 meters (30 feet) and 12 meters (40 feet), respectively. Plate VI-10 illustrates the space required for various disposal arrangements.

Disposition of this volume of material may alter surface drainage and underlying soil characteristics; i.e., percolation, oxygenation, etc., and relative water table depths. Material composition, general topography, climatic conditions, and mitigation measures employed will determine the degree of soil erosion and associated impacts, as well as leaching from the material. Existing land use will be precluded in the deposition area and the potential for future land use will be limited by modified conditions in the area. Soil fertility will, in all reality, be limited, but appropriate mitigative measures may permit growth of non-commercial vegetative cover.

Off-site disposal of excavated material may also result in transportation-related impacts. Over 600,000 truckloads of excavation material would require disposal, which would result in a significant impact to ambient air quality and noise levels. If public highways are utilized, increased traffic volumes will



* METERS OF UPPER RESERVOIR WATER FLUCTUATION

MAIN

PLATE VI-10

create the potential for traffic congestion, safety problems, and roadway deterioration. Other means of transportation will result in comparable increases in hydrocarbon emissions and increased traffic in the respective transportation routes; e.g., rivers and railways.

6.4.2 Heat Dissipation

In conventional pumped storage schemes, heat is added to the system's generating water volume by the generating/pumping equipment. In a UHPS system, additional heat is transferred from the warmer subsurface geological formations in which the lower reservoir is located. Subsurface temperatures may increase at rates ranging from 1.0°C/100 meters of depth to 5.0°C/100 meters of depth, depending on the geographical location. A lower reservoir, several hundred meters underground, represents an increase in system water temperatures with the magnitude of the change dependent on the volume and configuration of the lower reservoir, as well as the duration of heat transfer. Heat transferred from representative generation/pumping equipment to cycling water has been calculated to be slightly in excess of 0.3°C.

The discharge of this warmer water into the upper reservoir will result in an initial change in the thermal stratification of that water body. Subsequent cycling and mixing of the water will produce a thermal equilibrium in dedicated upper reservoirs with minimal make-up resulting from geological-mechanical sources. In natural surface reservoirs, where more than minimal make-up water requirements constitute the inflow, surface water inflows will create temperature differentials near the point of inflow, although the volume and velocity of the flow will determine the characteristics of the thermal plume in the reservoir and its impact on overall temperature.

The magnitude of the long-term change in system temperature will be governed by total surface area and volume of the upper reservoir, ratio of cycled to uncycled water volumes, and ambient water and air temperatures. A pronounced temperature change of a natural upper reservoir may result in changes in ecological composition at both the levels of micro and macro biota. Such modifications may occur both in the reservoir, and downstream from the reservoir, if warmer water from the warmer upper reservoir is discharged into an existing stream. In addition, elevation of the surface water temperature can accentuate local fog and mist conditions under certain climatic conditions.

6.4.3 Water Quality

The principal source of change in water quality in a UHPS system are temperature and physical composition of the underground reservoir rock chamber. The cycling of water from the upper to lower reservoirs during the generation phase typically includes the transfer of micro organisms as well as water plants and fish. The lightless, low-oxygen conditions of the lower reservoir and the passage through generating equipment will result in killing of fish, as well as damage to micro organisms and plants. Bacterial action on these dead organisms will further deplete the oxygen supply and result in an increased nutrient level in the water returned to the surface reservoir. The residual water and organic deposits remaining in the chamber between cycles will accelerate the nutrification process in the fresh water of subsequent cycles. When this nutrient-rich water is returned to the surface reservoir, accumulations of algae may occur in the vicinity of the discharge, with a secondary accumulation of fish.

A second source of impact on water quality is the mineralization of water, either through direct leaching from the reservoir walls or through seepage from adjacent rock. The former is unlikely in the configuration involving a man-made cavern since a high quality stable rock formation will be utilized. A suitable natural cavern may present a greater opportunity for mineralization of the system water. Seepage through fractures in otherwise stable geological structures also present the opportunity for chemical concentrations in the system water. Rates of mineralization and inflows to the upper reservoir will determine the iron concentrations and their effect on aquatic organisms in the reservoir and discharge streams.

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Sedimentation and suspension of solids in the upper reservoir by mixing during the pumping cycle also represent potential impacts on water quality. During the first months of system operation, the sedimentation associated with construction activities will be slowed in the settling process by regular mixing of reservoir waters during the pumping cycle. After the settling of these sediments, the volume of suspended solids in the upper reservoir will approximate those normally encountered in a natural water body without a pumped storage system.

Biological and chemical wastes generated during the construction, operation and maintenance of the UHPS project represent potential impacts to water quality and to groundwater. Wastes would include construction force sewage, petroleum-based products from construction equipment and generating/pumping turbines, and other industrial chemicals. Although these wastes could have profound consequences on the environment if permitted to enter in sufficient quantities, the total volume is expected to be low and overall impacts comparable with those associated with similar construction projects.

6.4.4 Effect on Groundwater

The construction of penstock and vent shafts between the surface and underground reservoirs will result in a pathway for possible pollution from the surface to the natural water table and a possible perforation of the water table base. Since the shafts, themselves, will be impermeable, two sources of contamination to groundwater may occur. The first would result from contamination of the groundwater from surface sources through seepage around the shafts to the local water table. The degree of contamination around the penstock shaft would be limited by the upper reservoir water quality near the point of intake. If the vent shaft surfaces on land, as opposed to the reservoir, any chemical or biological contaminants present could enter the groundwater. The capacity of a local aquifer to receive the contaminant(s), as well as the rate and range of contamination within the aquifer, will be a function of soil characteristics and waterflow within the aquifer.

The second potential impact to groundwater is the possible loss of water through perforation in the base of the aquifer. Flow would be to the penstock area with the net flow being to the underground reservoir. Assuming the UHPS system will be essentially watertight, outflow from the water table would cease after the initial filling of voids around the shafts and other underground construction. If the system is not watertight, continued outflows would result in the lowering of the local water table. Aquifer characteristics would determine the extent of the area impacted by the lower water table. It is expected that leakage would be minimal with only minor impact on the local groundwater.

If penstock shafts are not watertight and system water can enter the groundwater, an additional source of groundwater contamination could result. The seepage of nutrient-rich, warm or turbid water from the shafts and flow velocity within the aquifer would determine the magnitude of contamination.

6.4.5 Effect on Wildlife Resources

In addition to those impacts on wildlife previously addressed, the impacts to other aspects of the eco-system may result in impacts to aquatic and terrestrial fauna. In either UHPS arrangement requiring a dedicated upper reser-voir, vegetation and wildlife habitat will be lost to the project. Members of less mobile species of mammals, reptiles and amphibians may be eliminated, while more mobile species will be displaced to a new habitat. Increased predation may occur on these individuals in their new, unfamiliar habitat.

Principal impacts on aquatic fauna in natural upper reservoirs will result from the fluctuations in water levels and increased water temperature. These fluctua-tions can affect shoreline spawning species of fish and amphibi-ans by exposing those areas periodically for periods up to ten hours. During this time, eggs may become destroyed. Increased water temperatures may cause a change in species composition. Increased sedimentation during the initial period of project operation may also affect fish populations and species composition.

6.4.6 Visual Impact

A large construction project such as UHPS will result in short-term visual impact associated with the construction process and disposal operation. Long-term visual impact will be associated with changes in topography where excavated material is disposed and with dikes constructed to form a dedicated reservoir. Land loss to inundation may also represent a visual impact.

In those arrangements utilizing a natural upper reservoir, the only long-term impacts will be those associated with disposal areas.

6.4.7 Socio-Economic Impacts

The impacts to the economy caused by project development and the demands placed on social services during construction and operation are generally similar to those for any large power project. The magnitude of these impacts will depend on the number of construction workers, their length of stay, and the number of people associated with the project who become new residents in the area. It is more advantageous, environmentally, to locate a project within a reasonable distance of a large population or load center. In this way, skilled laborers may be available within commuting distance from the project and the total number of new non-resident construction workers and their families may be sharply reduced. As such, the total socio-economic impact to that community would be less than to a community receiving a totally non-resident work force. Impacts related to the construction force and operation and maintenance personnel will be addressed in terms of a totally non-resident work force.

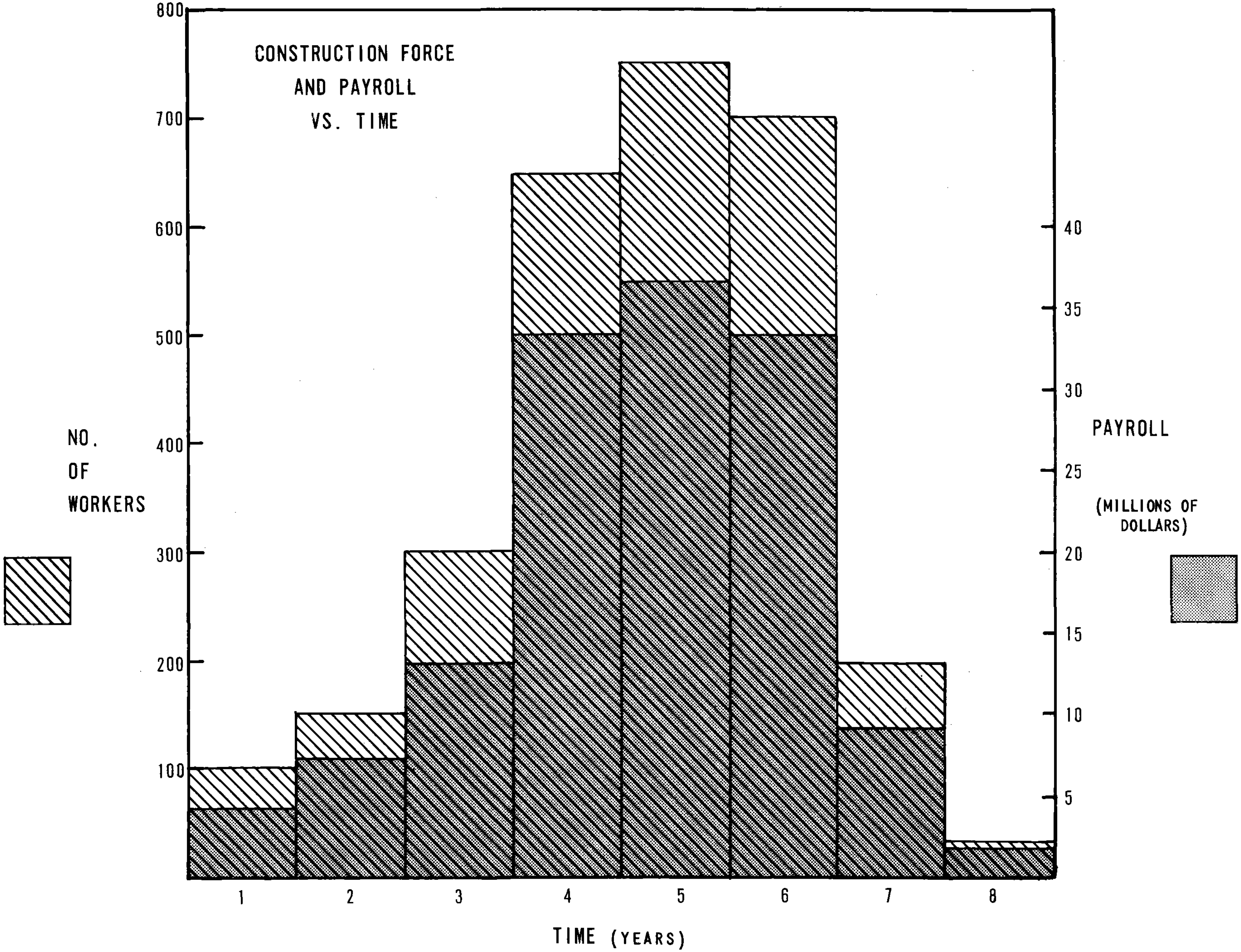
The most immediate impact to an area will be the dedication of land to the project, but the major impact to communities near the project area will be the influx of up to 750 workers, some of whom will be accompanied by their families. These non-residents will place demands on existing services and will expand existing markets for goods and services. Housing facilities, both temporary and permanent, will be in great demand. This increased demand will result in higher housing prices, as well as increased building and/or modifications to existing housing facilities. This new construction will increase the total community property tax base, resulting in increased tax receipts to local governments. Depending on the local property tax assessment procedures, property taxes of established local residents may increase due to a general increase in housing values. Low income families, especially those not associated with the construction project, may be displaced from existing housing by generally well-paid construction workers who represent potentially greater income to landlords.

The impact on the housing sector may be minimal if large numbers of temporary housing units are occupied only seasonally by tourists, skiers, etc. Year-round occupancy by construction workers would probably compensate for the loss of the more lucrative, but short-term, seasonal occupancy.

The magnitude of impact to the housing sector after the construction phase and during operation will depend on the design of the plant and the number of people required for its operation and maintenance. The project maintenance staff could vary from relatively few people for a remote controlled or highly computerized operation up to 100 for on-site control. For comparison purposes, a conventional pumped storage project in the 2000 MW range requires a staff of approximately 40 to 50 people for operation and maintenance. The operation and maintenance staff will be composed of highly trained supervisory personnel and technicians.

Another area of the economic sector which would be impacted by a UHPS project would be the commercial sales of goods and services. These include both sales of goods for actual project construction; e.g., construction supplies; and sales of goods and services to workers; e.g., clothing and foodstuffs. The magnitude of sales of construction goods will vary with the location of the project. If the project is near a metropolitan area where supplies are available, sales may be significant. If the UHPS project is located in a rural area, it may become necessary to "import" supplies from outside the project area, thus resulting in minor economic impact.

The sale of goods and services to workers and their families represents greater potential for income to the project area. As seen on Figure VI-11, approximate earnings of construction workers may reach $37,000,000 annually. Expansion of existing commercial establishments would be expected, as would the construction of new establishments to meet and take advantage of this potential market demand. This expansion would broaden the local tax base and would create new jobs, both in construction and sales. The total impact of a UHPS project on an area's economy would be difficult to predict, but total economic benefits will be greater than direct project-related expenditures.



MAIN

PLATE VI-11

Each dollar spent will generate other expenditures and growth in a "multiplier effect".

In addition to stimulation of the local economy through expenditures and taxes related to maintenance of the work force, tax receipts from the power utility can result in a significant impact on local government financing. Property taxes are generally a function of the value of land and "improvements" to that land. The "improvement" would be the UHPS facilities and appurtenant works representing a large investment. Property tax payments would be made from the initiation of project construction through the life of the project and can be expected to amount to several million dollars annually for the completed project. The magnitude of tax receipts and the impact to the area will depend on the tax structure, tax rates, etc.

The arrival of the construction force and families to the project area will place additional demands on existing area services, such as police protection, public education, fire protection, and medical services. A lack of careful planning and upgrading of existing services prior to project initiation will result in a decrease in the quality of service. Police departments may be faced with increased traffic control problems, schools with increased enrollments and a higher student/teacher ratio, and medical facilities with a shortage of doctors or hospital beds. Even if increased demand is anticipated, public funding may be inadequate to expand public services prior to project construction and receipt of tax revenues. The upgrading of social services requiring large investments; e.g., hospitals, to accommodate an influx of "temporary" residents may not be considered.

Utilities, such as electricity or municipal water, would also be impacted by increased demands of the construction work force. Costs of expanding these services would most certainly be passed on to all customers, including existing residents.

6.5 Measures to Mitigate Potential Environmental Impact

Although some degree of environmental impact is unavoidable in a UHPS project, measures can be taken to minimize impacts to the environment. Pumped storage requires more energy in the pumping cycle than is produced during generation. Therefore, pumped storage projects are a net consumer of energy and will result in additional environmental impacts associated with the power generation required to meet this net consumption. UHPS, as any other project that impacts the environment, will have general and specific impacts that can be addressed. Measures to mitigate the specific impacts of UHPS include siting, design, construction, and operation and maintenance.

6

6.5.1 Siting

In the initial phase, it is highly recommended that a major effort be placed on siting analysis in order to minimize constraints upon design, construction, and operation and maintenance of a UHPS project. Siting, utilized in an appropriate manner, may mitigate many of the impacts that could occur without proper consideration.

One of the major impacts dependent on the UHPS arrangement that is chosen will be the disposal of large quantities of excavated material. If a scheme with vast quantities of rock disposal is chosen, the first and foremost step taken should be an investigation of the region for possible economic use of the material. It is possible that an industry may be located that could utilize the disposal. Therefore, an economic offset would be provided for tunneling and excavation costs and alleviation of the disposal problem would also be provided. However, if this is not feasible, a suitable on or off-site disposal area will be required. A suitable area, either above or below ground (e.g., the use of an abandoned mine shaft or quarry) will have to be located within an economical distance. With the proper scheme chosen, Plate VI-10 will show the required area needed for the proposed height of fill. Utilizing on-site disposal, traffic safety for the local area will not be affected. Noise pollution will also be confined to the immediate area and air quality deterioration will be limited to a smaller region. It is very important that siting be addressed as an economic aspect in conjunction with its environmental impact.

Another important aspect of siting a UHPS project will be the availability of water and the quality of this water. Siting the project in a region of adequate water supplies will alleviate problems brought about through evapotranspiration. Concentration of nutrients and minerals in the discharge water would alter the ecosystem. Holding ponds may have to be constructed as a buffer before discharge into streams to maintain appropriate permit levels. Areas of high evaporation, groundwater, high rainwater accumulations, and other pertinent facts are shown on Plates VI-5 to VI-9. It can be seen that it is very important that siting be addressed to both economic and environmental evaluations.

6.5.2 Design

The design phase provides the necessary mitigative measures that are not relevant to siting address. One should not look at design as the second step, but as a co-partner to siting. Siting can eliminate many of the design problems and, conversely, design can eliminate the drawbacks of a site. For example, one cannot preclude the use of an existing reservoir because of the potential harm that may occur. Intake and discharge structures can be designed for minimal disturbance of the aquatic ecosystem. Aerators, designed and installed in appropriate places can maintain the level of O_2 in the upper and lower reservoirs. Eutrophication and fish kills could then be controlled and even eliminated through proper analysis and design of structures and their interaction with the environment.

Heat dissipation can be another important impact as related to design and siting procedures. As previously stated, geological heat ranges from $1.0^{\circ}C/100m$ to approximately $5.0^{\circ}C/100$ m, dependent on the geographical area. If a natural upper reservoir is used, heat dissipation ponds can be designed in order to meet permit requirements. Additional land would then be required in the siting process to provide for this dissipation. An energy-conscious consideration would be the utilization of this heat in required or recreational buildings as a heat source if enough heat is transferred to the water.

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6.5.3 Construction

The construction phase provides for the implementation, analysis and testing and, if needed, the modification, of designs for the project. Mitigative measures , such as sedimentation and erosion control basins, are provided during construction to maintain water quality levels in adjacent streams. Noise levels may be reduced by providing vegetative screens in the project area. Also, by siting the project in rolling terrain, noise levels may be decreased to the surrounding areas. However, noise problems should not be the sole criteria in siting a UHPS away from flat terrain. Provisions for sanitary and construction wastes will have to be undertaken. Either on-site treatment of liquid and solid waste or off-site treatment and disposal can be considered.

To properly alleviate or mitigate socio-economic problems in the public service sector, coordination and planning must be initiated before the start of the construction phase. With construction data and schedules in hand, the need for housing, food, public service organizations (such as police, fire, and hospitals) can be anticipated in cooperation with State, county and local officials. In this way, proper services can be provided without overburdening existing services.

6.5.4 Operation and Maintenance

During operation and maintenance in Cases 2 and 4, constant monitoring of incoming, confined, and outgoing water must be conducted. Only by constant monitoring of parameters associated with pollution can an ecosystem be maintained in a steady-state environment. Monitored parameters would include dissolved O_2, COD and BOD, turbidity, temperature variations, flows, both volume and velocity, and other standard tests to maintain the existing water quality. Water levels are another important parameter in these schemes during fish spawns. Developing eggs may not survive drastic fluctuations in water levels.

An attempt has been made to address the mitigative measures dealing with specific impacts of UHPS. It is assumed that all general impacts of construction projects and their mitigative measures are available to the reader. Only through proper planning, coordination and understanding of the scope of the project can specific impacts be addressed for a particular project.

6.6 Alternatives to UHPS

Sections 3, 4, and 8 of this report demonstrate that a UHPS facility in the 2000 MW, 10-hour generating range can, under varying site and system conditions, be both technologically and economically feasible. Earlier parts of this section discuss a variety of UHPS arrangements which may be utilized if certain conditions exist to enhance site compatibility and thus reduce significant adverse environmental impacts. This section compares these impacts to those which may be expected if an alternate source of energy was developed. Alternative sources include conventional hydro and pumped storage, internal combustion turbines, coal-fired steam, as well as nuclear power. Table VI-2 shows the basic criteria assumed for comparison.

6

6.6.1 Conventional Hydro

As shown on Table VI-3, only the Grand Coulee hydro project in Washington has a capacity in excess of 2000 MW. Only four other sites have generation capacity in excess of 1000 MW. Since land requirements for a 2000 MW plant are quite large (possible range of 4000 to 32,000 ha) and require an undeveloped reach of a major river system with sufficient head, potential for new development in this country (see FERC Report P43 - Ref. 5) is primarily limited to the State of Alaska. (Plate VI-12)

6.6.2 Conventional Pumped Storage

Conventional pumped storage plants in the 2000 MW generation capacity range are limited to one existing site, Consumer Power's Ludington Pumped Storage Project which has a maximum operating capacity of 1979 MW. There are presently three proposed sites for generation of 2000 MW. These sites are located in Virginia, New York and North Carolina (Table 13-FERC-P43). No attempt is made in this report by the FERC to identify potential pumped storage sites. Land requirements, water requirement and Federal, State and local regulatory agencies will limit the development of pumped storage projects.

6.6.3 Fossil-Fuel Plants

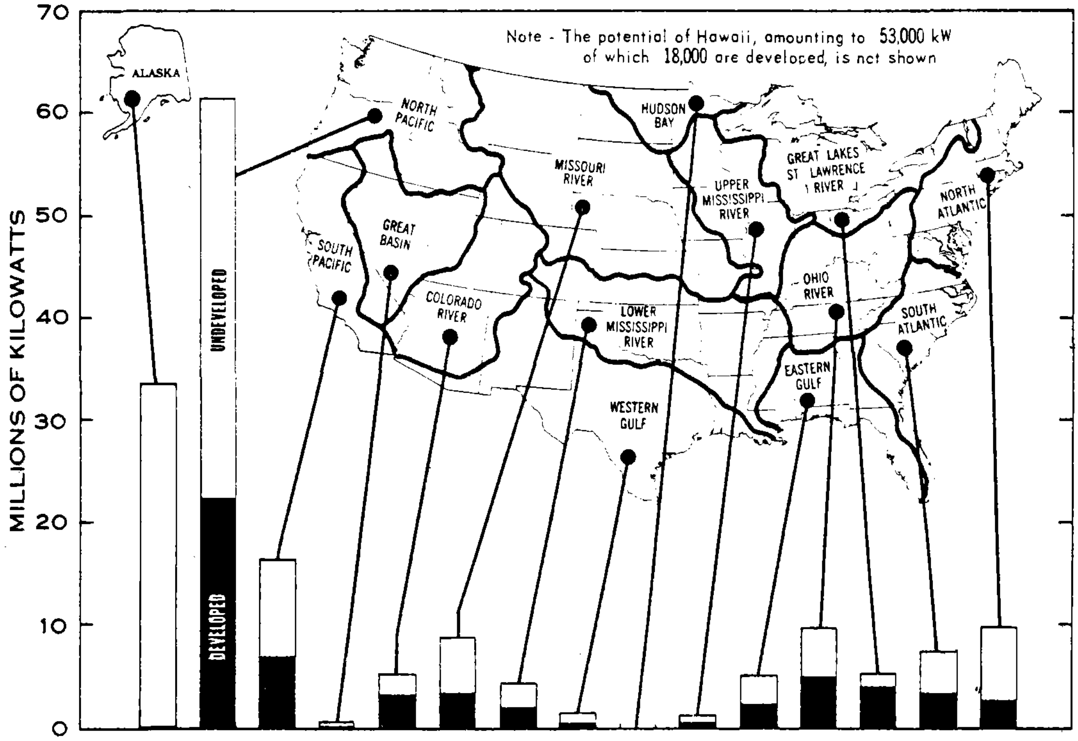
The prevalence of fossil-fueled plants is shown by the fact that 97 plants, each having a generation capacity greater than 1000 MW, are presently operating in the U. S. (FERC-1974). Of these 97, sixteen generate 2000 MW or more, with the largest generator being a 3,280 MW plant in Monroe, Michigan (FERC-1974). In siting a 2000 MW plant, air and water regulations, fuel availability, and transportation facilities will, in some cases, limit and eliminate potential sites. (Table VI-4)

6.6.4 Nuclear

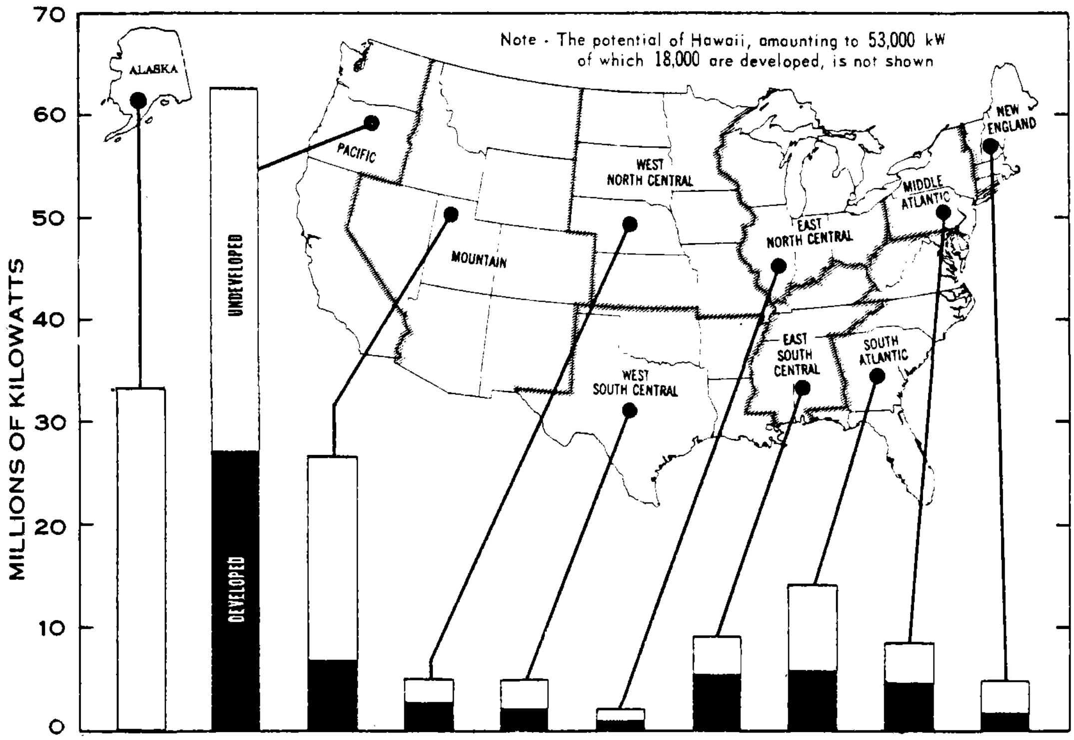
Nuclear power siting for a 2000 MW plant will require agreement with Federal, State and local environmental laws regulating air emissions, water quality and fuel

CONVENTIONAL HYDROELECTRIC POWER
DEVELOPED AND UNDEVELOPED - JANUARY 1, 1976

BY MAJOR DRAINAGES



BY GEOGRAPHIC DIVISIONS



Source:
Federal Energy Regulatory Commission

MAIN PLATE VI-12

availability, storage and disposal. At present, only three nuclear plants with a capacity greater than 2000 MW exist in the United States. These plants are located in Illinois, Pennsylvania and South Carolina. Potential areas for siting of nuclear plants have been established by the U. S. Nuclear Regulatory Commission (NECSS-1975) and can be used as a preliminary screening tool in the siting process. (Table VI-5)

6.6.5 Internal Combustion

At present, no known internal combustion generating plant exists with capacity greater than 1000 MW. The largest existing plant is located in Dania, Florida, and produces 822 MW of power. Siting for this facility is accomplished in conjunction with a base-loaded facility. Therefore, the siting potential is very high. However, since no facility over 1000 MW exists, it is very doubtful that a 2000 MW plant would be constructed (although this capacity need not be in one plant) in the near future, besides the problems of frequent outages and maintenance. (Table VI-6).

6.7 A Comparison of UHPS To Alternatives

Under the present state-of-the-art, UHPS must be considered as a peaking alternative to the more traditional modes of electric power generation, such as conventional hydro, conventional pumped storage, or nuclear, fossil or internal combustion power. Section 6.6 points out that few power complexes in the 2000 MW range exist today and, in the case of conventional hydro and pumped storage, the potential for new sites is non-existent in many parts of the country and relatively limited in all other parts, with the exception of the Pacific Northwest and Alaska. With regard to fossil and nuclear

TABLE VI-2

COMPARISON OF GENERAL CHARACTERISTICS

Modes of Generation	Land Requirements (Hectares)	Capital Cost ($/kw)	Fuel Costs (cents/10^6 Btu)	Major Environmental Impacts	Construction Schedule (months from initiation) Finish1/	Construction Schedule (months from initiation) Commercial Operation	Number of Existing Plants (1000 MW or Greater)	Potential Siting of Plants (1000 MW or Greater)
UHPS (2000 MW)	40-120	$325	During Pumping Cycle Oil: 180-230	Water	93	96	0	**High**
Conventional Hydro	4000-32,000	$500-700	---	Water and Land	48	52	5 (FPC-74)	**Low**
Conventional Pumped Storage (1000 MW)	300-4000	$300-350	Pumping Cycle Oil: 180-230	Water and Land	48	57	3 (FPC-74)	**Low**
Nuclear	40-80	$800-1000	45-55	Water and Air Health and Safety	60	66	9 (FPC-74)	**Med**
Fossil	50-150 (On-site coal storage)	$640-Coal	Coal: 70-110 Oil: 180-230 Gas: 80-120	Water and Air Health and Safety	42	42	97 (FPC-74)	**Med**
Internal Combustion	**Usually used as a peaking unit in conjunction with a base loaded facility**	$450-Oil	Oil: 180-230 Gas: 80-120	Noise and Air (NO_x)	18	18	0 (FPC-73)	**High**

1/ Does not include time delays for regulatory licensing process.

SOURCE: Ref. 5, 6, 8, 9

TABLE VI-3

DEVELOPED AND UNDEVELOPED HYDROELECTRIC PLANTS AND SITES FOR 1000 MW OR MORE

State	Site	River	Owner	Developed Installed Capacity - MW	Undeveloped Potential Capacity - MW
Alaska	Wood Canyon	Copper			3600
Alaska	Yukon-Taiya Site	Taiya			3200
Alaska	Sitkine River	Sitkine			2260
Alaska	Crooked Creek	Kuskokwin			2140
Alaska	Woodchopper	Yukon			2160
Alaska	Rampart	Yukon			5852
Alaska	Ruby	Yukon			1460
Alaska	Holy Cross	Yukon			2800
Idaho	Lower Canyon	Salmon			1376
Idaho	Crevice	Salmon			1280
New York	Robert Moses	Niagara	PASNY	1954	--
Oregon	John Day	Columbia	Corps of Engineers	1957	--
Washington	Dalles	Columbia	Corps of Engineers	1807	--
Washington	Grand Coulee	Columbia	Bureau of Reclamation	2200	3320
Washington	Chief Joseph	Columbia	Corps of Engineers	1024	1045

PUMPED STORAGE PROJECTS OVER 1000 MW

State	Site	River	Owner	Developed Installed Capacity - MW	Undeveloped Potential Capacity - MW
Massachusetts	Northfield	Connecticut	West. Mass. Electric Co.	1000	
Michigan	Ludington	Lake Michigan	Consumer Power	1979	
New York	Blenheim-Gilboa	Schoharie Creek	PASNY	1000	

TABLE VI-4

STEAM ELECTRIC PLANTS

FOSSIL-FUELED

State	Site	River	Owner	Installed Capacity MW
Georgia	Bowen	Etowah	Georgia Power Co.	2546
Kentucky	Paradise	Green	T. V. A.	2558
Michigan	Monroe	Lake Erie	Detroit Edison	3280
Missouri	Labadie	Missouri	Union Electric	2482
Ohio	Sammis	Ohio	Ohio Edison	2456
Ohio	Stuart, J.M.	Ohio	Columbus & S. Ohio	2441
Tennessee	Cumberland	Cumberland	T. V. A.	2600
Texas	Cedar Bayou	Galveston Bay	Houston Lighting & Power	2295
Texas	Robinson, P.H.	Galveston Bay	Houston Lighting & Power	2315

TABLE VI-5

NUCLEAR POWER

State	Site	River	Owner	Installed Capacity MW
Illinois	Zion	Lake Michigan	Commonwealth Edison Co.	2196
Pennsylvania	Peach Bottom	- - - -	Philadelphia Electric C.	2304
South Carolina	Oconee	Keowee	Duke Power	2660

TABLE VI-6

INTERNAL COMBUSTION

GAS TURBINE GENERATORS

State	Site	River	Owner	Installed Capacity MW
Florida	Lauderdale		Florida Power & Light Co.	822
Georgia	McManus #3 & 4		Georgia Power Co.	499
New York	Astoria		Con. Edison Co.	745
New York	Gowanus		Con. Edison Co.	688
New Jersey	Essex		P. S. Electric & Gas Co.	585
New Jersey	Burlington		P. S. Electric & Gas Co.	521
New Jersey	Kearny		P. S. Electric & Gas Co.	517
New Jersey	Edison		P. S. Electric & Gas Co.	502
Pennsylvania	Richmond		Philadelphia Electric Co.	730
Tennessee	Allen		T. V. A.	621

development, new sites must have an adequate water supply and meet stringent air quality regulations. Particular attention must also be given to the cost of fuel, transportation of fuel to the site, and for facilities to treat or dispose of spent fuel by-products such as fly ash or nuclear wastes. Internal combustion power generation is only viable in locations in the country where fuel costs are competitive.

In this regard, the future looks extremely bright for UHPS. Many of the traditional environmental impacts associated with air and water pollution can be virtually eliminated through careful siting and implementation of a compatible design arrangement. UHPS provides a flexibility unavailable to many alternatives which are dependent on a continuous supply of surface water in areas meeting air quality standards. UHPS breaks this tradition in that the site, while dependent upon suitable subsurface rock formations, need not be located in close proximity to an existing surface water supply if modest amounts of surface water can be diverted for initial fill-up and make-up, or if sufficient groundwater or subterranean sources can be tapped. Using an artificial upper (surface) reservoir, it is possible to establish a closed system with no off-site waste water discharges. Excess rock disposal offers many opportunities to construct water supply storage areas and waste disposal settling basins. This siting flexibility can further reduce costs of environmental impacts through the selection of locations close to existing and planned high voltage transmission networks and established transportation corridors. These off-site impacts are considered in the overall regulatory review process, a process which can add appreciably to project costs when extreme environmental situations are encountered and causing those preceding to extend over long periods of time.

APPENDICES

A. Heat Input Calculations

B. Required Initial Fill-up Time

C. Required Make-up Water

D. References

6

APPENDIX A

HEAT INPUT CALCULATION

6

APPENDIX A

Heat Input Calculation to the Reservoir from Powerplant Equipment

Rated Capacity = 2000 MW

Total Energy Output Per Year

- 50 yr. Pumping Energy	153,072 GWh
- 50 yr. Energy Generation	117,866 GWh
	35,206 GWh
1 yr. Average Energy Generation	2,357 GWh

Total Energy Input 2,367 GWh ÷ 0.77 = 3,061 GWh

Energy Loss/Yr = 3061 - 2357
= 704 GWh

In addition, losses in the transformer = 0.005 x (3061 + 2357)
= 27.09 GWh

Total Energy Loss = 704 + 27.09 GWh
= 731 GWh

Assuming 95% of total heat loss is transmitted to the water, total heat input into the water is:

0.95 x 731 GWh = 694 GWh

Assuming operation is uniform and consistent throughout the year, the average daily input into the reservoir will be:

694 GWh/365 days = 1.90 GWh/day

Converting to Btu/day = 6,485 million Btu/day

Employing 5800 acre feet = 1.577×10^{10} of water

6485 million lbs - $^{o}F/1.577 \times 10^{10}$ lbs of water = $0.4^{o}F$

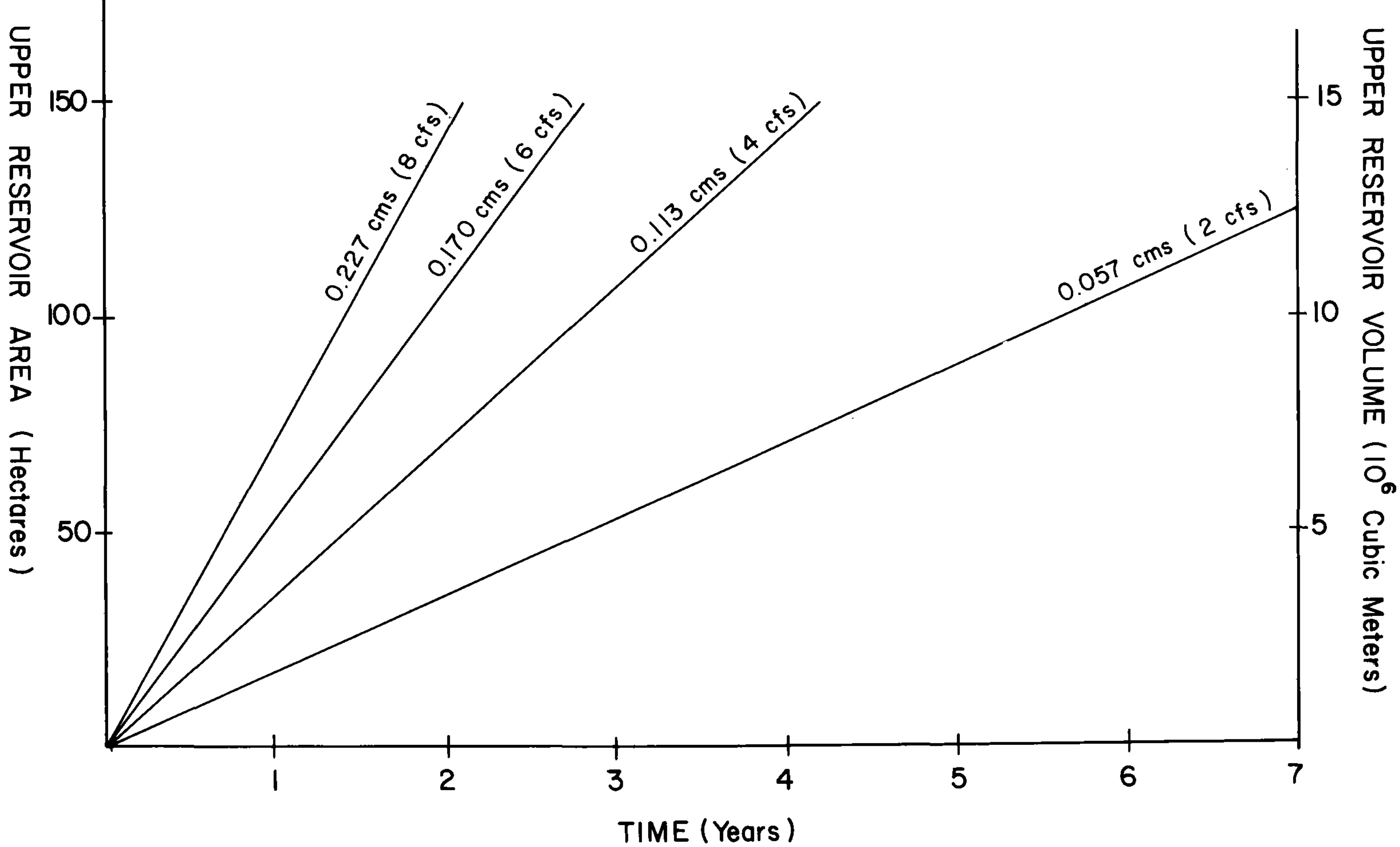
APPENDIX B

REQUIRED INITIAL FILL-UP TIME

6

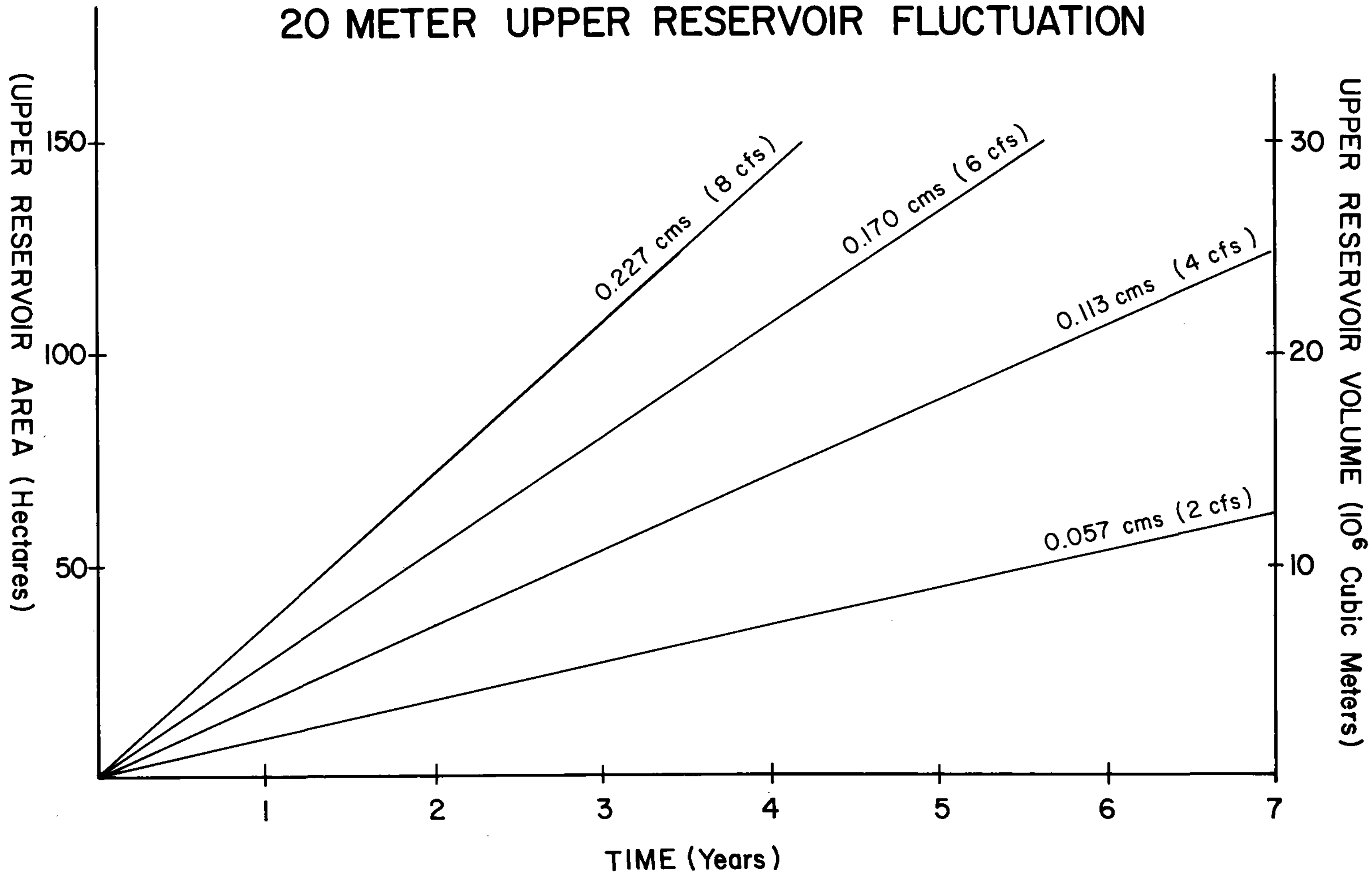
REQUIRED INITIAL FILL UP TIME FOR UPPER RESERVOIR

10 METER UPPER RESERVOIR FLUCTUATION



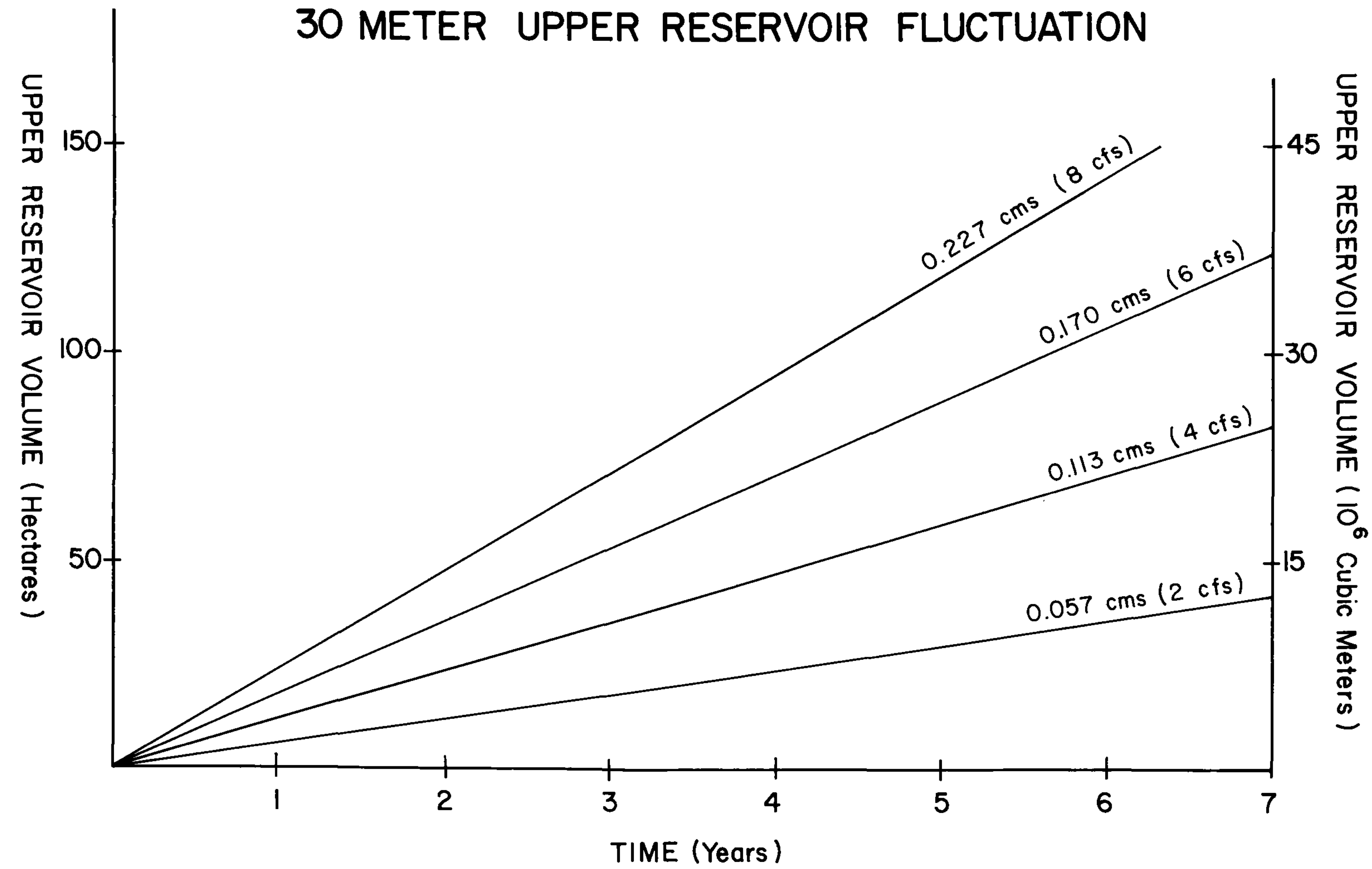
REQUIRED INITIAL FILL UP TIME
FOR UPPER RESERVOIR

20 METER UPPER RESERVOIR FLUCTUATION



REQUIRED INITIAL FILL UP TIME FOR UPPER RESERVOIR

30 METER UPPER RESERVOIR FLUCTUATION

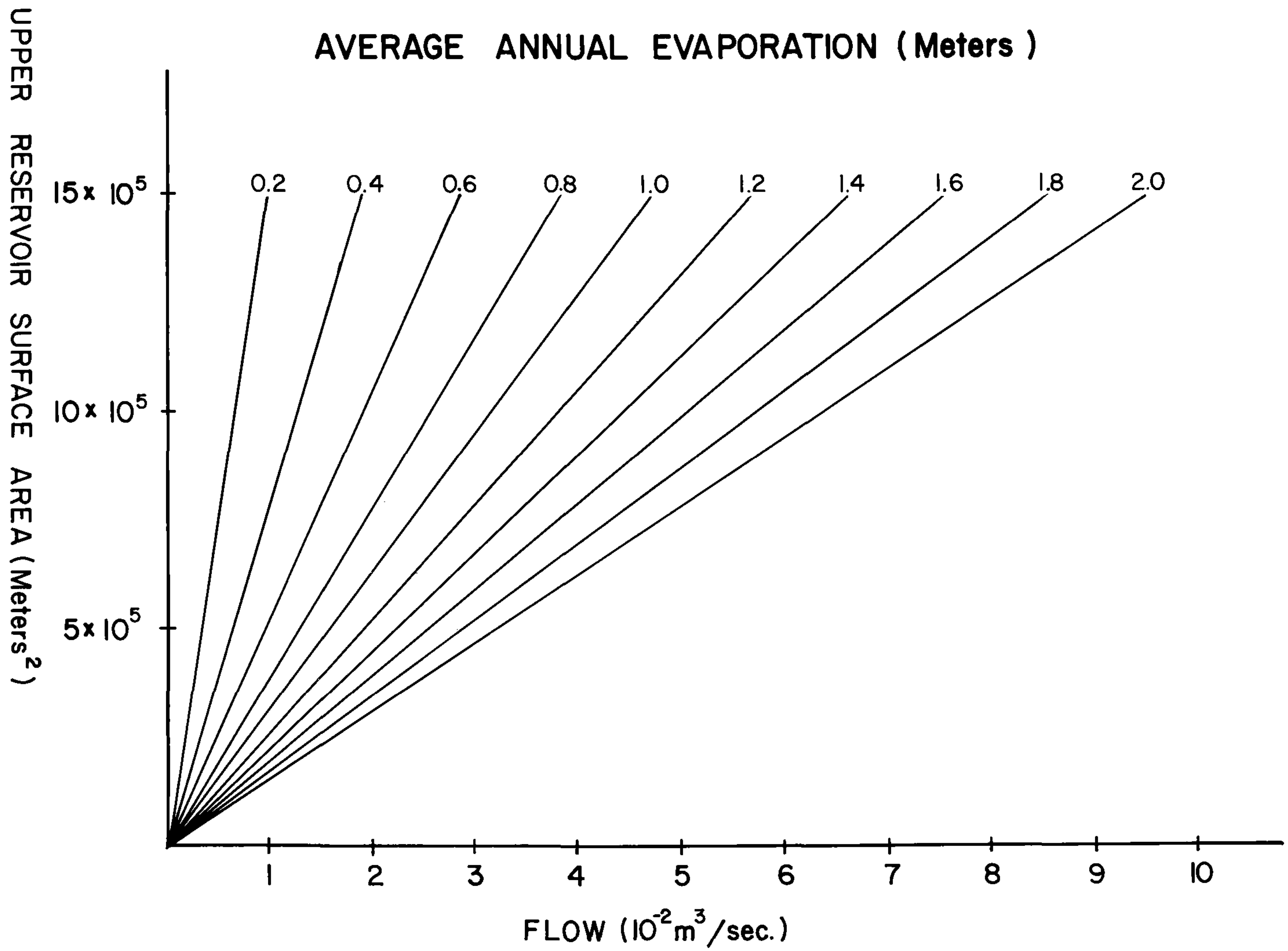


APPENDIX C

REQUIRED MAKE-UP WATER

6

REQUIRED MAKE UP WATER



APPENDIX D

REFERENCES

6

REFERENCES

1. Hill, I. K. and Willett, D. C.
   "Environmental Impact of Underground Pumped Storage"
   Paper presentation at the Engineering Foundation
   Conference, Rindge, N. H. August 1975

2. U. S. Water Resource Council
   "The Nation's Water Resources". Washington, D. C. 1968

3. Flint & Skinner
   "Physical Geology". 1974

4. Gerkowski, R. F. and Dellas, J. J.
   "Generation Challenge - Ludington Pumped Storage"
   Proceedings of the American Society of Civil Engineers,
   Vol. 104, No. PO1, February 1978.

5. Federal Power Commission
   "Hydroelectric Power Resources of the United States - Developed and Undeveloped". FPC P-43, 1976.

6. Federal Power Commission
   "Steam Electric Plant Construction Cost and Annual Production Expenses". Twenty-Seventh Annual Supplement. Washington, D. C. 1974.

7. U. S. Nuclear Regulatory Commission
   "Nuclear Energy Center Site Survey - 1975".
   National Technical Information Service
   Springfield, Virginia. January 1976.

8. Federal Power Commission
   "Gas Turbine Electric Plant Construction Cost and Annual Production Expenses". FPC-S-254. 1973

9. New England Regional Commission
   "Power Facility Siting Guidelines in New England"
   Energy Program Technical Report 75-8. Boston, Mass.
   January 1976.

7.0 TOTAL ENERGY REQUIREMENTS

7.1 General

The energy requirements set forth herein are for a UHPS project of 2,000 MW capacity, 1,200 m (4,000 ft.) head, 10 hours of storage, Scheme I (multi-stage reversible units) as shown in Chapter 4. The estimate is in two parts: part one includes the energy expended during construction; part two covers the energy consumed during operation over a period of 50 years. Also included for comparison are similar computations for an equivalency of 4-500 MW coal-fired cycling plants (CFCP).

7.2 UHPS Energy Requirements During Construction

Most mobile construction equipment is powered by diesel engines. An estimate of energy used requires an analysis of total horsepower consumed. To this must be added different energy sources to provide power for furnishing compressed air, electricity, water power, tunnel lighting, concrete plant(s), hoists, and other services. Table VII-1 lists the project features and an estimate of the energy absorbed by each feature.

7.3 Methodology for Upper Reservoir

The following methodology was used in estimating the energy used in the construction of the Upper Reservoir (civil works above ground). To provide a basis of comparison with a constructed reservoir, the horsepower hours for mobile equipment used in the construction of the Blenheim-Gilboa Pumped Storage Project, New York, for a given dollar value of

Table VII - 1

SCHEME 1. 2000 MW - 6 UNITS

ENERGY USED IN CONSTRUCTION OF UHPS FOR POWER, WATER, COMPRESSED AIR AND MISCELLANEOUS

	POWER DEMAND					LOAD DURATION		TOTAL ENERGY
Project Feature	Construction Equipment	Compressed Air	Ventilation	Hoists	Total KW	Months	Hours	Total KWH
Shaft - Power	(1)	224	76	4332	4632 KW	23	14,242	65,969,000
Shft - Access	(1)	224	76	4332	4632 KW	27	16,718	77,438,000
Shaft - Cable	(1)	224	76	4332	4632 KW	23	14,242	65,969,000
Shaft - Ventilating	(1)	224	76	4332	4632 KW	18	11,146	51,628,000
Lower Reservoir Heading	2270 KW	549	4623	9747	17,190 KW	-	6,264	107,678,000
Lower Reservoir Bench	2270 KW	1268	4623	9747	17,900 KW	-	18,576	332,510,000
Powerhouse Excavation	2000 KW	746	2000	8664	13,410 KW	-	9,240	123,908,000
Other Underground Features	1000 KW	746	2000	5415	9161 KW	12	7,430	68,066,000
Penstocks								
Draft Tubes								
PH Civil								
PH Elec. & Mech.								
Upper Reservoir								27,208,000
Miscellaneous					3000 KW	60	37,152	111,456,000
Concrete Plant								
Tunnel Lighting								
Shops								
Pumps, Dewatering								
Water Supply								
Total Energy Used in Construction of UHPS								1,031,830,000

(1) Included

construction based on a given median year of construction was selected.

The diesel horsepower hours were tabulated and their cost at that time escalated by indices to January 1977.

7.4 Cost of Blenheim-Gilboa Upper Reservoir, Median Construction Year 1971

B-G escalated to July 1977 = $\$49{,}532{,}000 \times \frac{411}{241} = \$84{,}472{,}000$

Cost of UHPS Upper Reservoir and Roads, January 1977 price level

$27,331,000

Cost of UHPS Upper Reservoir and Roads Escalated to July 1977: $\$27{,}331{,}000 \times \frac{411}{393} = \$28{,}583{,}000$

B-G Upper Reservoir Unit HP-HRS:

$$\frac{107{,}829{,}432\text{(HP-HRS)}}{\$84{,}472{,}000} = 1.276 \text{ HP-HRS/\$1}$$

$\therefore$ UHPS Upper Reservoir = $28,583,000 x 1.276 =
$36,472,000 HP-HRS
36,472,000 x 0.746 = 27,208,000 kWh

7.5 Lower Reservoir

In developing the energy that would be used in the construction of the underground reservoir, an analysis was made of the power and energy demands of: the mobile construction equipment, the compressed air requirements, the ventilation requirements and the hoist requirements.

Typical analyses of the power demand for these construction services follow:

7

7.5.1 Lower Reservoir Heading

Construction Mobile Units:

10 cy LHD: 12x180 hp =	2160 hp
D6 Dozer: 1 x 259 hp =	259 hp
Cat 120 Grader: 1 x 125 hp =	125 hp
2 Crushers: 2 x 250 hp =	500 hp
	3044 hp = 2270 kW

7.5.2 Compressed Air: Compressed air is assumed as the source of power for rock drilling equipment. In general, compressors require about 1 hp to compress 5 cfm.

1-3/4" drills: 32 ea x 115 cfm = 3680 cfm

$$3680 \text{ cfm} \times \frac{1 \text{ HP}}{5 \text{ cfm}} = 736 \text{ hp}$$

736 hp x 0.746 = 549 kW

7.5.3 Ventilation

$\frac{67 \text{ men}}{\text{shift}}$ x 75 cfm =	5,025 cfm
3044 hp (equipment) x $\frac{75 \text{ cfm}}{\text{hp}}$ =	228,300 cfm
Total	233,825 cfm

233,325 cfm ÷ 4 headings = 58,330 cfm per heading

48" pipe size and 100 Bhp fans spaced 1100'

$$\frac{70{,}000' \text{ total length}}{1{,}100' \text{ spacing}} = 64 \text{ fans}$$

64 fans x 100 Bhp = 6400 hp

6400 hp x 0.7467 = 4775 kW

7.5.4 Hoists

The required drive horsepower per hoist is 5,810 root mean square. The estimate is based on 4,000' hoisting depth with an available hoisting time of 19.5 hours per day and a double drum production hoist, skip capacity of 24 tons, rope size of 2.0 inches, full speed velocity of 2,840 fpm.

Mucking hoists:	2 x 5810 hp x 0.746 =	8669 kW
Personnel hoist:		1083 kW
		9752 kW

7.6 Energy Content of the Permanent Equipment, Materials and Expendables in Project

The total January 1977 construction costs of the UHPS Scheme I broken down into percentage component costs of hydro projects, the percentage having been derived from empirical costs, yields (based on B-G, Shiroro, and Bureau of Labor Statistics)

	% of Construction Cost	Scheme 1 1977 Energy-Related Costs
Owner Materials[1]	16.3	$ 77,104,000
Contractor Materials	20.3	96,025,000
Labor	15.9	Not Applicable
Expendables, Equip. Repair & Operation	17.9	84,672,000
Constructor's Equip. & Plant	9.4	44,465,000
Overhead & Profit	20.2	Not Applicable
	100.0%	$302,266,000

Note: Construction Cost (1977) = $473,029,000

The U. S. Average energy cost of good is 80,942 BTU per 1967 dollar value[2]. The dollar values are producers' prices including a mark-up to retail price, about 66%. Therefore, energy content equals:

$$\frac{180}{393} \text{ (Escalation } \frac{1/67)}{1/77} \times \$302{,}266{,}000 \times 80{,}942 \text{ BTU/\$} \times 34\% = 3.81 \times 10^{12} \text{ BTU}$$

$$\frac{3.81 \times 10^{12}}{3413} = 1.12 \times 10^{9} \text{ kWh}$$

Footnotes:

(1) Includes turbines, generators and all auxiliary permanent equipment.

(2) Ref: Annual Review of Energy Vol. 1, 1976, Table 13, page 502. The energy content of selected goods and services in 1971. Source: Bullard, C.W. 1973 Energy Conservation Through Taxation Dec. No. 95 Center for Advanced Computation, University of Illinois, Urbane.

The tables list 36 products, a partial list, indicating the corresponding energy intensity for each product. The energy content of the products varies from 15,477 BTU/$ for doctors, dentists to 218,097 BTU/$ for plastics.

The average energy intensity of 80,942 BTU/$ was arrived at on the basis of the following analysis of weighted averages of energy intensities of the most appropriate categories which were substituted for cost components.

Absorption	Cost Components (Products)	BTU/$	% Const. Cost 1/77	Energy Related Cost 1/77	% Energy Related Cost
E1	Fabricated Metal Products	91,977	(20.3+16.3)	$173,129,000	57
E2	Motor Vehicle & Parts	70,003	17.9	84,672,000	28
E3	New Residential Construction	60,218	9.4	44,465,000	15

The energy related costs in 1976 prices:

$$\frac{180}{393} \times \$302,266,000 = \$138,443,000$$

$$E1 = 0.34 \times 57\% \times 91,977 \times \$138,443,000 = 2.47 \times 10^{12} \text{ BTU}$$
$$E2 = 0.34 \times 28\% \times 70,003 \times \$138,443,000 = 0.92 \times 10^{12} \text{ BTU}$$
$$E3 = 0.34 \times 15\% \times 60,218 \times \$138,443,000 = 0.42 \times 10^{12} \text{ BTU}$$
$$\overline{3.81 \times 10^{12} \text{ BTU}}$$

$$\text{Average BTU/\$} = \frac{3.81 \times 10^{12} \text{ BTU}}{\frac{180}{393} \times 302,266,000 \times .34}$$

7.7 Energy Required for Mobilization and Freight

Total 1977 value of equipment and materials = $302,266,000
Freight & mobilization at 1976 price level before markup:

$$5\% \times \$302,266,000 \times \frac{180}{393} \times 34\% = \$2,354,000$$

Energy absorption in freight & mobilization:

$$80,942 \frac{\text{BTU}}{\$} \times \$2,354,000 = 0.19 \times 10^{12} \text{ BTU} = 5.57 \times 10^{7} \text{ kWh}$$

7.8 Summary of Construction Energy Requirements Represented by Completed UHPS Project

Construction Operations	1,031,830,000 kWh
Mobilization (Freight)	55,700,000
Equipment and Materials	1,120,000,000
	2,207,530,000 kWh =
	2.2×10^9 kWh

7.9 Coal Fired Cycling Plant (CFCP)

7.9.1 Energy Requirements During Construction

The 1977 cost of 4 x 500 mw coal-fired plants excluding escalation and interest during construction and contractors overhead and profit:

$$\frac{\$750}{kW} \times 2{,}000{,}000 \text{ kW} = \$1{,}500{,}000{,}000$$

Contingencies	6.7%
Engineering Ser.	2.2%
Client Overhead	.7%
	9.6%; say 10.0% = indirect construction cost

Total direct 1977 construction cost of plants
90% x $1.5 billion = $1.35 billion

Breakdown of total 1977 direct construction cost into percentage component costs of coal-fired plants (the percentages were derived from empirical cost data):

Cost Component	% Direct Construction Cost	1/77 Energy Related Cost
Labor	30%	Not Applicable
Turbine, Generator & Materials	66%	891,000,000
Construction Equipment	4%	54,000,000
	100%	$945,000,000

a. Energy absorption in the construction of civil work items:

Site work, earth work. concrete: 3.5% x $945,000,000 = $33,075,000

0.95 kWh of energy were used per 1977 dollar value of construction on the Blenheim-Gilboa project. Therefore, for $33,075,000 value of civil works for coal-fired plants, the energy absorption would be:

$$0.95 \frac{\text{kWh}}{\$} \times 33{,}075{,}000 = 31{,}421{,}000 \text{ kWh}$$

b. Energy absorptions by miscellaneous services:

	Power Demand
Concrete Plant	1000 kW
Shops	1500 kW
Water Supply, etc.	500 kW
	3000 kW

Energy requirement - 3,000 kW x 4 yrs. x 40% load factor

$$\times 12 \frac{\text{mo}}{\text{yr}} \times 4.3 \frac{\text{wk}}{\text{mo}} \times \frac{\text{6 day}}{\text{wk}} \times \frac{\text{24 hours}}{\text{day}} = 35{,}666{,}000 \text{ kWh}$$

Total energy used in 4 coal-fired cycling plants (500 kW each) construction operations

Energy used in construction of civil works items	31,421,000 kWh
Energy used for miscellaneous service	35,666,000 kWh
Total	67,087,000 kWh

7.9.2 Energy Content of the Permanent Equipment, Materials and Expendables Incorporated in Project

Energy Absorption	Cost Components	BTU/$	% Const. Cost 1/77	Energy Related Cost 1/77	% Energy Related Cost
E1	Fabricated Metal Products	91,977	66%	891,000,000	94.3%
E2	Motor Vehicle & Parts	70,003	4%	54,000,000	5.7%
				$945,000,000	100.0%

Energy absorption for equipment and materials:

$$E1 = 0.34 \times 94.3\% \times 91,977 \times 945,000,000 \times \frac{180}{393} = 1.28 \times 10^{13} \text{ BTU}$$

$$E2 = 0.34 \times 5.7\% \times 70,003 \times 945,000,000 \times \frac{180}{393} = .06 \times 10^{13} \text{ BTU}$$

$$1.34 \times 10^{13} \text{ BTU} \times .000293 = 3,962,200,000 \text{ kWh}$$

7.9.3 Energy Required for Mobilization and Freight for Equipment and Materials Incorproated in Project

Total 1977 value of equipment & material = $945,000,000

Assume freight & mibilization 5% x $945,000,000 x $\frac{180}{393}$ x 34% = $7,358,000

Energy absorption = 80,000 $\frac{BTU}{\$}$ x 7,358,000 = 0.59×10^{12} BTU

$.59 \times 10^{12}$ BTU x .000293 = 172,372,000 kWh

7.9.4 Summary of Energy Requirements Represented by Completed CFCP Project

Construction Operations		67,087,000 kWh
Equipment and Materials (including freight and mobilization)		4,134,672,000 kWh
	Total	4,201,759,000 kWh

7.10 Comparison of Energy Required During Construction

	2,000 MW, 10 HR UHPS (kWh)	4 - 500 MW Coal-fired Cycling Plants (kWh
Construction Operations	1,031,830,000	67,087,000
Equipment and Materials (including freight and mobiiization)	1,175,700,000	4,134,672,000
Total	2,207,530,000	4,201,759,000

7

7.11 Energy Requirements During Operation

7.11.1 UHPS - 2,000 MW

Energy requirements for UHPS are calculated based on the assumption of full utilization during a fifty (50) year life term.

Scenario A (8-hour reservoir)

Year 1 energy generation	518 GWh
Year 2 energy generation	1,350 GWh
Year 3 energy generation	952 GWh
Year 4 and beyond generation	1,175 GWh
50-year pumping energy	82,944 GWh
50-year energy generation	58,045 GWh
Net 50-year energy loss	24,899 GWh

(See Table VII-2 for basic data)

Scenario D (6-hour reservoir)

Year 1 energy generation	630 GWh
Year 2 and beyond generation	1,046 GWh
50-year pumping energy	74,497 GWh
50-year energy generation	51,884 GWh
Net 50-year energy loss	22,613 GWh

(See Table VII-3 for basic data)

7.11.2 4 - 500 MW Coal-Fired Plants

Energy requirements for the coal-fired cycling plants are based on the assumptions that the generation mix of the system in the future does not drastically differ from the existing mix.

Scenario A

	Output GWh
Year 1	5,827
Year 2	10,748
Year 3	11,251
Year 4 and beyond	10,155
50-year total	505,111 GWh

Scenario D

	Output GWh
Year 1	5,992
Year 2 and beyond	11,959
50-year total	591,983 GWh

(See Table VII-5 for basic data)

7

TABLE VII - 2

UHPS SCENARIO A PUMPING & GENERATION

WEEKLY PUMPING AND GENERATION ENERGY (MWh)

	Summer*	Spring/Fall*	Winter*
1989			
Pumping	36,024	1,264	0
Generation	25,212	880	0
1990			
Pumping	80,264	19,592	1,264
Generation	55,936	13,788	880
1991			
Pumping	49,928	19,592	3,792
Generation	34,992	13,788	2,654
1992			
Pumping	67,624	18,960	1,896
Generation	47,392	13,272	1,382

*For this scenario, the year consists of 3 winter months, 5 summer months, and 4 spring/fall months of 4 weeks each.

TABLE VII - 3

UHPS SCENARIO D PUMPING & GENERATION

WEEKLY PUMPING AND GENERATION ENERGY (MWh)

	Summer*	Spring/Fall*	Winter*
6-Hour Reservoir			
1989			
Pumping	20,382	18,486	17,538
Generating	14,260	12,940	12,346
1990			
Pumping	34,128	30,336	30,336
Generating	23,886	21,098	21,098
8-Hour Reservoir			
1989			
Pumping	20,371	23,226	21,330
Generating	14,260	16,262	14,931
1990			
Pumping	37,821	32,706	32,706
Generating	26,475	22,825	22,825
10-Hour Reservoir			
1989			
Pumping	20,382	23,700	23,700
Generating	14,260	16,573	16,573
1990			
Pumping	40,290	35,076	35,076
Generating	28,199	24,544	24,544

*The calendar year consists of 3 summer months, 6 spring/fall months and 3 winter months of 4 weeks each.

7

TABLE VII - 4

CFCP SCENARIO A

MONTHLY OUTPUT (MWh)

	1989	1990	1991	1992
JAN	276,339	820,575	1,082,965	811,620
FEB	501,298	745,569	924,484	727,392
MAR	553,550	1,099,280	883,524	1,101,332
APR	471,428	1,065,364	1,048,692	1,068,500
MAY	303,309	707,503	674,350	894,670
JUN	504,292	1,001,435	991,882	963,838
JUL	537,240	1,041,223	1,034,311	1,020,508
AUG	548,692	1,060,234	1,046,846	1,043,567
SEP	484,960	932,070	904,530	870,181
OCT	557,074	1,095,764	818,331	1,018,457
NOV	538,108	1,060,725	845,124	830,976
DEC	550,810	818,523	996,379	813,780
	1,000 MW Inst. (776 Rated)	2,000 MW (1552 Rated)	2,000 MW (1552 Rated)	2,000 MW (1552 Rated)

TABLE VII - 5

CFCP SCENARIO D

MONTHLY OUTPUT (MWh)

	1989	1990
JAN	557,948	1,096,717
FEB	505,926	759,243
MAR	419,140	836,838
APR	404,495	1,066,544
MAY	536,286	1,083,800
JUN	542,078	1,080,472
JUL	569,774	1,135,656
AUG	562,622	1,122,616
SEP	534,412	800,067
OCT	417,740	1,108,492
NOV	394,625	853,649
DEC	548,338	1,014,438
	1,000 MW Inst. (776 Rated)	2,000 MW Inst. (1552 Rated)

7

8.0 SIMULATED POWER SYSTEMS ANALYSIS

8.1 Introduction and Summary

As has been shown in Section 4.6.2 and summarized in 1.5, the investment cost of UHPS makes it competitive with conventional pumped storage as a source of stored peaking energy. From a system standpoint, UHPS is equivalent to conventional pumped storage, or other storage schemes used for peak shaving.

System studies were conducted to evaluate the economy of a particular pumped storage plant operating in a specific utility system to compare the total cost of owning and operating this plant to the cost of owning and operating one or more alternative generating schemes with the same reliable capacity.

The systems used in this study have been taken from the EPRI report entitled "Synthetic Electric Utility Systems for Evaluating Advanced Technologies" (February 1977). The criteria used to determine the suitability of the systems for the development of a large pumped storage plant were the presence of large quantities of economical coal-fired and nuclear base-load generation, expensive oil-fired peaking generation, and minimal existing pumped storage capacity. On this basis, Scenario A and Scenario D of the EPRI report were selected as being more suitable to pumped storage operation.

Results of the system studies and economic analysis show that UHPS offers substantial savings in investment cost over coal-fired cycling units, and substantial savings in system production cost over gas turbines. The total present worth of system operation cost plus alternative unit investment cost, for the 50 year life of the UHPS plant, for both Scenarios, are shown below:

SCENARIO A	TOTAL PRESENT WORTH ($ Millions)	DIFFERENTIAL PRESENT WORTH ($ Millions)
UHPS	51922.7	0.0
Coal Fired Cycling	54036.0	2113.3
Gas Turbines	51931.7	9.0
SCENARIO D		
UHPS (6 hr. reservoir)	35344.7	0.0
Coal Fired Cycling	36900.8	1556.1
Gas Turbines	36011.4	666.7

It is seen that, while UHPS is more economical than coal fired cycling units in both systems, the economy of UHPS over gas turbines differs greatly depending upon the system.

8.2 Systems Selected

The two systems selected were Scenario A and Scenario D. These regions appear most conducive to effective utilization of UHPS because of the opportunities to pump with low cost power at night and on weekends, and to displace costly combustion turbine power during weekday peak periods. Details of the scenario loads and generation from Reference 9, Table II-2, are reproduced as Appendices A and B (at the end of this section).

8.3 System Characteristics

The generation schedules and the loads specified for Scenarios A and D are assumed to be as of the year 1988.

Scenario A, with an installed generation capacity of 53,350 MW, consists of 60 percent coal-fired steam and 21 percent nuclear units which provide inexpensive base generation; 7 percent oil-fired steam units, 9 percent internal combustion turbines and 3 percent conventional, and pumped hydro plants which supply the peak power. Scenario D, with an installed capacity of 32,000 MW, has a smaller proportion of low cost base generation in comparison with Scenario A. It consists of 36 percent coal-fired steam and 24 percent nuclear units for base generation. Oil-fired steam supplied 26 percent and internal combustion turbines provide 14 percent of the total generation capability. More detailed information regarding existing generation of Scenarios A and D are shown in Appendices A and B.

The load shapes in Scenario A, with a peak of 46,640 MW, and in Scenario D, with a peak of 27,720 MW, are very similar. The main difference is the relatively lower load levels during the weekends in the summer months in Scenario A. Weekly load and load-duration curves for the three typical months of the year are shown in Appendices A and B.

8.4 Systems After 1988

An annual load growth of 6 percent per year, starting from the 1988 values of 44,000 MW for Scenario A, and 26,000 MW for Scenario D, was considered. This growth rate is used in the case study, EPRI report Appendix B,"Synthetic Utility Systems for Evaluating Advanced Technologies," February 1977. The additional generation capacity required for load growth will be provided by nuclear, coal fired steam, underground pumped storage, and coal fired cycling units. The underground pumped storage installation is staged in two years. The first stage, with 1000 MW capacity, will be operational in 1989, followed by another 1000 MW coming on-line in 1990 for a total of 2000 MW of underground pumped storage. The generation

TABLE VIII-1

UNDERGROUND HYDROELECTRIC PUMPED STORAGE PROJECT

SCENARIO A - FUTURE LOAD GROWTH AND GENERATION EXPANSION PLANS FOR UNDERGROUND HYDROELECTRIC PUMPED STORAGE (UHPS) AND THERMAL ALTERNATIVES

Year	Peak MW	Installed Capacity	Installed Cap./Peak	Base Capacity: Nuclear MW %	Base Capacity: Base Coal MW %	Cycling Capacity: Oil MW %	Cycling Capacity: C.T. MW %	Cycling Capacity: PS & Hydro MW %	Cycling Capacity: UHPS or Cycling Coal	Additional Capacity MW	
1988	44,000	53,350	1.21	11,240 (21)	32,000 (60)	4,250 (08)	4,250 (08)	1,610 (03)		------	-----
1989	46,640 (+2,460)	56,550 (+3,200)	1.21	12,440 (22)	33,000 (58)	4,250 (08)	4,250 (08)	1,610 (03)	1,000 (02)	1000 UHPS or 1200 Nuclear 1000 Coal	1000 Coal Cycling 1200 Nuclear 1000 Coal
1990	49,440 (+2,800)	59,950 (+3,400)	1.21	13,640 (23)	34,200 (57)	4,250 (07)	4,250 (07)	1,610 (03)	2,000 (03)	1000UHPS or 1200 Nuclear 1200 Coal	1000 Coal Cycl. 1200 Nuclear 1200 Coal
1991	52,400 (+2,960)	63,550 (+3,600)	1.21	14,840 (23)	35,400 (56)	4,250 (07)	4,250 (07)	1,610 (03)	3,200 (05)	1200 Coal 1200 Nuclear 1200 Coal Cycling	
1992	55,550 (+3,150)	67,350 (+3,800)	1.21	15,840 (24)	36,400 (54)	4,250 (06)	4,250 (06)	1,610 (02)	5,000 (07)	1000 Coal 1000 Nuclear 1800 Coal Cycling	

TABLE VIII-2

UNDERGROUND HYDROELECTRIC PUMPED STORAGE PROJECT

SCENARIO D - FUTURE LOAD GROWTH AND GENERATION EXPANSION PLANS FOR UNDERGROUND HYDROELECTRIC PUMPED STORAGE (UHPS) AND THERMAL ALTERNATIVES

				Base Capacity		Cycling Capacity			Additional Capacity	
		Installed		Nuclear	Base Coal	Oil	C.T.			
Year	Peak MW	Capacity MW	Installed Cap./Peak	MW %	MW %	MW %	MW %	UHPS or Cycling Coal	MW	
1988	26,200	32,000	1.22	8,000 (25)	11,200 (35)	8,000 (25)	4,800 (15)		-----	-----
1989	27,720 (+1,570)	33,920 (+1,920)	1.22	8,920 (26)	11,200 (33)	8,000 (24)	4,800 (14)	1,000 (03)	1000 UHPS or 920 Nuclear	1000 Coal Cycling 920 Nuclear
1990	29,430 (+1,660)	35,950 (+2,030)	1.22	8,920 (25)	12,230 (34)	8,000 (22)	4,800 (13)	2,000 (06)	1000 UHPS or 1030 Coal	1000 Coal Cycling 1030 Coal

expansion plans considered for Scenarios A and D are shown in Tables VIII-1 and VIII-2. These generation expansion plans are consistent with United States' energy policies of slef-sufficiency and increased use of domestic energy resources. The plans maintain the overall ratio of peaking and base operation to the total system installed capacity as found in 1988.

The generation expansion plan for Scenario A is continued beyond 1990 until the entire pumped storage capacity in the system is economically operational. However, in Scenario D the entire 2000 MW of underground pumped storage capacity was absorbed economically in the first two years.

The load shapes used for the study are the same as the ones for 1988 on the assumption that the present load characteristics will remain the same. The system loads are modeled for the computer programs as four typical days: Saturday, Sunday, Peakday, and four similar weekdays. The load shapes considered for Sundays are also used for holidays. Each of these four typical days are represented by twelve two-hour load levels.

8.5 System Analysis Method

Peak load requirements in 1989 in the Scenarios selected are to be met by means of new generation staged to provide the system energy requirements at a pre-established degree of reliability. When a new unit is added, it must satisfy the immediate system needs, but consideration need also be given to its future performance which will vary with time. As the load grows, more units are added and the economics of the new units are assessed within the framework of a generation expansion plan as a whole, rather than on an individual unit or plant basis.

Several plans are developed using units of different types and sizes that provide similar abilities to fulfill the system needs. Their economic evaluation can be, and is confined purely to a cost comparison of alternatives. Investments and operating costs for each plan are calculated and the resulting cash flows discounted at interest rates based on the opportunity cost of capital. The plan with the lowest costs in terms of present worth is considered the economic choice.

The operating portion of the costs are obtained by representing the generation to be added along with existing generation and the system load characteristics in a computer model that simulates the system operation and arrives at a calculation of the production costs. The benefits resulting from the displacement of high cost energy required during the peak hours by low cost energy stored during the off-peak hours are a function of the generation cost of the thermal units operating in the system. The benefits are a function of the timing in which the energy tradeoffs are to be made. This timing, in turn, depends upon the system load cycle.

The determination of the optimum capacity of a specific pumped storage plant within a given utility system is an economic decision which must be based not only on the system load curve, but also on the system generation mix and future generation expansion. Even relatively minor changes in the system generation can cause a difference in the economic choice of pumped storage capacity. Since this study is not made for a specific utility with a fixed generation expansion, it was decided that a plant of 2000 MW, representative of the capacities of conventional pumped storage plants planned and being built in the United States, would be a reasonable assumption. This assumption was discussed with USBR Representatives at the meeting of June 30, 1977, and agreed to by letter of August 3, 1977.

8.6 Alternatives

8.6.1 UHPS

8.6.1.1 Physical Characteristics of the Underground Pumped Storage Plant

The pumped storage considered for Scenario A has a capacity of 2000 MW. It is a one-stage, one-drop pumped storage installation with six 330 MW units. The pumped storage considered for Scenario D is a two-stage, cascaded pumped storage installation with two underground power plants and reservoirs. This installation has four 250 MW units at the intermediate level and another four 250 MW units at the lower level. Both Scenarios have a 1200 m (4000 ft.) head.

The intermediate reservoir in Scenario D introduces an operational limitation due to its small volume which will not permit operation of a single unit for a long period of time. At least two units must be operated simultaneously, one in the intermediate and one in the lower stage.

8.6.1.2 Pumped Storage Operation in the System

Economic dispatching of pumped storage in the generation mix is a function of all other generating capacity in the system. This does not necessarily coincide with the maximum possible utilization of the pumped storage. Therefore, to optimize the production cost of the system, the economic operating limits of the pumped storage are first determined and it is operated only within these limits.

The UHPS plant in both Scenarios is allocated to the load curve on the basis of the incremental cost of thermal unit generation. Since UHPS has a cycle efficiency of 70%, the incremental cost of the energy displaced by UHPS generation must be greater than 1.43 (1.0/0.7) times the incremental cost of the energy used for pumping. Tables of incremental costs at various load levels were generated by a computer program which simulates the loading of the system hydro and thermal units. These tables, for the three typical months of 1990 in Scenario D, and 1991 in Scenario A, are shown in Tables VIII-3 and VIII-4. The incremental costs were then used to determine where on the weekly load shape it would be possible to pump, and where it would be possible to generate.

In Scenario A, after the economic levels of operation were determined, it was noted that during all winter, spring and fall months, only weekend pumping was economical. This was mainly due to the excessive amounts of nuclear and coal-fired generation capacity in the system which results in a uniform array of incremental costs for most load levels. This is contrary to the condition required for maximum operation of a pumped storage plant which requires a fairly large cost differential between peak and off-peak generation.

During the summer months, however, due to the higher peak loads, a proper combination of weekend and weekday pumping proved to be very economical in utilizing the entire capacity of the underground pumped storage.

TABLE VIII-3

INCREMENTAL COSTS OF GENERATION

SCENARIO A – 1991

(AUGUST)		(NOVEMBER)		(DECEMBER)	
GEN. LEVEL (MW)	INC. GEN. COST ($/mWh)	GEN. LEVEL (MW)	INC. GEN. COST ($/mWh)	GEN. LEVEL (MW)	INC. GEN. COST ($/mWh)
9681.0	3.920	8757.0	3.920	9261.0	3.920
10609.9	4.108	9545.8	4.108	10125.9	4.108
11229.8	4.233	10335.2	4.295	10991.4	4.295
12006.2	4.358	11370.4	4.420	12128.7	4.420
12757.1	4.420	12008.8	4.483	12829.8	4.483
13507.9	4.483	12605.8	4.608	13255.2	4.545
14214.4	4.608	13424.5	4.858	13929.6	4.733
14936.6	4.795	14014.1	6.983	14604.1	4.920
15813.0	5.045	14832.0	7.295	15370.0	7.170
16445.0	7.233	15536.9	7.483	16074.9	7.358
17384.9	7.483	16476.9	7.733	16779.8	7.545
18089.8	7.670	17132.7	7.920	17718.8	7.795
18769.7	7.858	17776.8	8.108	18351.6	7.983
19624.8	8.108	18644.1	8.358	19218.5	8.233
20275.3	8.295	19294.6	8.545	19868.9	8.420
21142.6	8.545	20085.6	8.795	20518.6	8.608
21744.1	8.733	20843.7	9.045	21283.1	8.858
22502.2	8.983	21716.7	9.106	22041.2	9.108
23850.9	9.274	22405.9	9.106	23129.3	9.231
24496.7	9.106	23095.1	9.106	23844.0	9.231
24699.0	9.168	23784.3	9.106	24558.8	9.231
26046.2	9.356	24980.3	9.231	25754.8	9.356
26786.5	9.356	25487.2	9.356	26495.2	9.356
27526.8	9.356	26342.7	9.390	26991.9	9.390
28267.2	9.356	27060.4	9.390	27709.6	9.390
29007.5	9.356	27989.4	9.515	28625.4	9.515
29511.1	9.390	28733.4	9.515	29369.4	9.515
30228.8	9.390	29477.4	9.515	30113.4	9.515
31170.2	9.515	29849.5	9.515	30485.4	9.515
31914.2	9.515	30593.5	9.515	31229.5	9.515
32658.2	9.515	31337.5	9.515	31973.5	9.515
33030.3	9.515	32410.8	9.765	33020.5	9.765
33774.3	9.515	33207.5	9.765	33817.2	9.765
34518.3	9.515	34004.2	9.765	34613.9	9.765
35616.4	9.765	34402.6	9.765	35012.2	9.765
36413.1	9.765	35199.3	9.765	35808.9	9.765
37209.8	9.765	36131.6	9.886	36728.6	9.886
37608.2	9.765	37199.7	10.136	37746.4	10.318
38404.8	9.765	37820.0	16.818	38325.0	17.068
39201.5	9.765	38242.0	17.068	38638.0	17.993
40358.1	10.015	38833.3	18.993	39400.3	19.993
40865.2	9.890	39549.6	19.993	40063.6	20.493
41261.2	9.886			41310.8	24.091
42638.0	11.068			41723.6	24.341
43214.0	17.068				
43527.0	17.998				
44339.1	19.493				
44952.6	20.493				
46428.6	24.341				
46612.6	24.341				
47384.8	25.341				
47972.0	26.341				
48787.3	28.341				

August: 52400 – Peak Load

November: 40800 – Peak Load

December: 41900 – Peak Load

TABLE VIII-4

SCENARIO D - 1990

INCREMENTAL COSTS OF GENERATION

(FEBRUARY)

GEN. LEVEL (MW)	INC. GEN. COST ($/MWh)
4697.0	3.916
5275.7	4.168
5772.7	4.356
6400.3	4.481
6775.0	4.668
7279.3	4.981
7720.3	7.543
8197.1	8.163
8729.0	8.918
9545.4	9.105
9710.7	9.293
10234.6	9.106
10730.5	9.606
11256.7	10.015
11741.6	10.515
12540.7	10.015
12965.3	10.015
13390.0	10.015
13814.7	10.015
14239.4	10.015
14884.6	10.515
15228.2	18.063
15727.9	19.381
16303.9	19.568
16803.0	19.993
17346.9	20.493
17923.2	20.993
18207.0	20.993
18711.2	21.493
19262.1	21.993
19932.5	21.993
20267.7	21.993
21192.9	23.591
21412.6	24.091

21200 Peak Load

(APRIL)

GEN. LEVEL (MW)	INC. GEN. COST ($/MWh)
3960.0	3.918
4558.6	4.231
5097.4	4.418
5486.9	4.543
5971.3	4.918
6490.0	7.418
6978.3	7.856
7487.4	8.356
7975.0	8.856
8897.9	9.106
9251.5	8.856
9503.2	9.043
10146.2	9.265
10879.3	9.515
11251.4	9.515
11623.4	9.515
11995.4	9.515
12847.0	10.015
13111.4	9.515
13483.4	9.515
14361.6	16.818
14573.4	17.068
15004.9	18.068
15463.8	19.381
16152.7	20.493
16668.8	20.493
17199.0	20.993
17482.7	20.993
18012.6	21.493
18589.3	21.993
19192.0	22.493
19884.6	23.841
20295.6	24.341

20000 Peak Load

(JUNE)

GEN. LEVEL (MW)	INC. GEN. COST ($/MWh)
5434.0	3.918
5942.0	4.108
6455.6	4.293
7075.6	4.418
7452.1	4.481
8022.5	4.731
8506.5	4.981
8972.0	7.418
9460.3	7.856
9969.4	8.356
10457.0	8.856
10982.0	9.418
11878.1	9.606
12069.1	9.106
12438.5	9.418
13145.0	9.356
13460.9	9.606
14050.7	10.015
14475.3	10.015
14974.6	10.515
15749.3	10.015
16174.0	10.015
16598.7	10.015
17023.4	10.015
17448.0	10.015
18117.6	10.515
18461.2	18.068
19180.9	19.068
19458.1	19.443
20036.0	19.993
20579.9	20.493
21156.2	20.993
21440.0	20.993
21944.2	21.493
22495.1	21.993
23165.5	21.993
23500.7	21.993
24425.9	23.591
24931.3	24.341
25059.3	24.341
25446.0	24.841
26019.1	25.841
26516.7	26.341
26967.4	27.841

27350 Peak Load

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Considering the amount of energy which could economically be generated by the pumped storage, it was decided that the reservoir size should be just large enough to provide for weekend pumping during winter, spring and fall months. After careful study of the amount of energy which could be economically generated, and the size of a reservoir which would permit weekend pumping, it was concluded that 8 hours of reservoir would satisfy the requirements. Appendices C-1 through C-6 show the energy displaced by the underground pumped storage utilizing 8 hours of reservoir in 1989 and 1990 and operating within the economic limits.

In contrast to the system in Scenario A, the system in Scenario D absorbed the pumped storage very effectively, and it could utilize different size reservoirs through a proper combination of weekday and weekend pumping, Therefore, it was decided that the system in Scenario D should be studied for a range of reservoir size (6, 8 and 10 hours) and the resultant savings in the operation costs with larger reservoirs be weighed against the additional investment required. Appendices D-1 through D-4 show the energy displaced by the underground pumped storage in 1989 and 6 hours of reservoir and in 1990 with 6, 8 and 10 hours.

8.6.2 Coal Fired Cycling Plant

8.6.2.1 Physical Characteristics of the Coal Fired Cycling Plant

The coal fired cycling plant consists of four 500 MW units, two of which will be in service in 1989 and the other two in 1990. These units which are designed for cycling at the peak load are among the most efficient units on the system.

Coal fired cycling units have an estimated lifetime of 30 years. Typical heat rates of a 500 MW coal cycling unit for different generation levels are shown below:

PERCENT CAPACITY	HEAT RATE (Btu/kWh)
25	10,844
40	9,913
60	9,359
80	9,117
100	9,050

8.6.2.2 Coal Fired Cycling Operation in the System

Production costs of the thermal alternatives were calculated in the same way as for the pumped storage alternatives -- that is, first, all the existing conventional and pumped hydro plants in the system were allocated on the load curve. Maintenance schedules considering forced and unscheduled maintenance of the units were developed to insure maximum possible reliability and minimum operating cost.

The units were then dispatched on the load curve, based on the equal incremental generation costs. Calculation is done for every two hour load increment. Start-up costs of the thermal units are represented in Btu's of fuel used by each thermal unit to reach synchronous speed.

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It should be noted that the position a thermal unit takes on the load shape is a function of both its efficiency and its fuel cost, if production costs are to be minimized. Because of its low fuel cost and its size, the coalfired cycling unit is one of the most economical fossil units in the system. Unless it is artificially constrained to operate at a smaller capacity factor, this unit will be operated almost continuously.

8.6.3 Combustion Turbine Operating Characteristics

8.6.3.1 Physical Characteristics of the Combustion Turbine Plant

The combustion turbine alternative consists of forty 50 MW units, twenty of which will be in service in 1989, the other twenty in 1990. The units are the same as those already in service in both Scenarios. A lifetime of 20 years has been assumed. Typical heat rate of a 50 MW combustion turbine is 14,000 Btu/kWh. These units are not normally run at partial load.

8.6.3.2 Combustion Turbine Operation In the System

Production cost calculation for the combustion turbine alternative was made in the same way as that for the UHPS and CFCP alternatives.

8.7 Present Worth of All Associated Fixed and Variable Costs - UHPS and Alternatives

Detailed calculations of variable operating costs were made for the period of 1989 and 1990 for the alternative plans in Scenario D, and 1989 through 1992 in Scenario A. Costs prior to 1989 are common to all alternative plans and are therefore not included.

Production costs of the alternative plans in both scenarios were determined by computer simulation of thermal unit operation. These costs were based on the assumption that each system required 1200 MW of spinning reserve (equal to the largest unit size in the system). The pumped storage in Scenario A with 8 hours of reservoir, and in Scenario D with 6, 8 and 10 hours were allocated (within the limits determined in the previous section) on the load curves.

Next, the effective capacity of all thermal units were determined to reflect forced and unscheduled maintenance outage. Yearly maintenance schedules for the thermal units in the Scenarios were developed to maintain a levelized annual reserve margin. Table VIII-5 shows the duration of scheduled and unscheduled outages of thermal units.

The yearly production costs of both systems with pumped storage were calculated, assuming that only thermal units smaller than 600 MW can be shut down overnight or during weekends, resulting in a higher generation cost for low load levels. This happens when the total capacity of all thermal units of 600 MW and greater exceeds the load. These units are then forced to operate at less than full capacity, therefore at a lower efficiency. The off-peak pumping of the underground pumped storage corrects this situation. It was also recognized that units smaller than 600 MW in capacity will use a certain amount of energy to reach synchronous speed from standstill. The thermal units were then allocated on the load curve, based on the equal incremental loading concept to supply the load.

In Scenario A, by 1990 full capacity of underground pumped storage could be utilized only during the summer months, so it was considered necessary to calculate the production cost until the full capacity could be economically utilized during most of the year. Therefore, the production costs for 1991 and 1992 were also calculated.

Fuel costs and operation and maintenance costs are shown in Tables VIII-6 and VIII-7.

Fixed operation and maintenance costs considered for the UHPS, coal-fired cycling, and combustion turbine plants were based on FERC figures[1/], escalated to 1977 cost levels. These costs are shown below:

UHPS Fixed O&M[2/]	-	$1,753 per MW per year
Coal-Fired Cycling Fixed O&M	-	3,777 per MW per year
Combustion Turbine Fixed O&M[3/]	-	1,913 per MW per year

1/ "Hydroelectric Power Evaluation, Supplement No. 1", 1969

2/ Conventional pumped storage O&M costs - UHPS costs are not available

3/ Based on four units per plant

TABLE VIII-5

UNDERGROUND PUMPED STORAGE STUDY

ESTIMATED OUTAGE RATES OF

EXISTING AND FUTURE THERMAL UNITS

THERMAL UNITS	INSTALLED CAPACITY (MW)	SCHEDULED MAINTENANCE (WEEKS)	FORCED OUTAGE AND UNSCHEDULED MAINTENANCE (% OF YEAR)
Coal Fired Steam	50.	2	4.9
Coal Fired Steam	200.	3	10.3
Coal Fired Steam	400.	4	15.5
Coal Fired Steam	600.	4	22.4
Coal Fired Steam	1,000.	5	23.8
Coal Fired Steam	1,200.	5	23.8
Coal Fired Cycling	500.	4	22.4
Coal Fired Cycling	600.	4	22.4
Oil Fired Steam	200.	3	10.3
Oil Fired Steam	400.	4	15.5
Oil Fired Steam	800.	5	23.8
Internal Combustion Turbine	50.	1	25.7
Nuclear	1,000.	5	16.0
Nuclear	1,200.	5	16.0
Hydro			
CPS	-	2	1.2
UHPS	-	5	5.0 *

* Based on limited data

TABLE VIII-6

THERMAL UNITS

FUEL COSTS (JANUARY 1977)

Unit	Fuel Cost
Nuclear	$ .45/MBtu
Coal Fired Steam	$1.00/MBtu
Coal Fired Cycling	$1.00/MBtu
Oil Fired Steam	$2.30/MBtu
Combustion Turbine	$2.59/MBtu

Source: Suggested by Bureau of Reclamation - Letter of August 3, 1977.

TABLE VIII-7

THERMAL UNITS

VARIABLE OPERATION AND MAINTENANCE COSTS (JANUARY 1977)

UNIT	CAPACITY (MW)	OPERATION AND MAINTENANCE COSTS ($/MWH)
Coal Fired Steam	50	0.62
Coal Fired Steam	200	0.54
Coal Fired Steam	400	0.46
Coal Fired Steam	600	0.37
Coal Fired Steam	1,000	0.27
Coal Fired Steam	1,030	0.26
Coal Fired Steam	1,200	0.22
Coal Fired Cycling	500	0.47
Coal Fired Cycling	600	0.40
Oil Fired Steam	200	0.45
Oil Fired Steam	400	0.38
Oil Fired Steam	800	0.24
Combustion Turbine	50	2.50
Nuclear	1,000	0.18
Nuclear	1,200	0.16

Source: Ref. 9, Table II-2

Investment costs of the underground pumped storage plants were developed by MAIN, based on current market prices and labor costs in the U. S. (January 1977 cost levels). The cash flows of these costs over the construction period are shown in Tables VIII-8 and VIII-9.

Investment costs of the coal-fired cycling plants were based on the figure of $1000.00 per kW as recommended by the Bureau of Reclamation.1/ Annual disbursement of these costs is shown in Table VIII-10.

Investment costs of the combustion turbines were based on a figure, supplied by the Bureau of Reclamation,2/ of $160 per kW. These units are assumed to be installed in one year, therefore their disbursement consists of a single payment in the year during which they become operational.

A figure of 3.8 percent was used as the "real" cost of capital. This corresponds to a weighted cost of capital of 10 percent and an inflation rate of 6 percent (1.10/1.06 = 1.038), and represents the cost of money in the absence of future inflation.

The 1989 present worth of the alternate investments was obtained by future-worthing the investment disbursements to the end of 1989. This single sum was then converted into an annual fixed charge, using an interest rate of 3.8 percent, a typical value of 2 percent for taxes and insurance (2.2 percent for gas turbine), and a sinking fund factor of 0.7 percent for UHPS (50 years), 1.85 percent for CFCP (30 years), and 3.43 percent

1/ Letter dated August 3, 1977

2/ Letter dated August 3, 1977

TABLE VIII-8

UNDERGROUND PUMPED STORAGE STUDY
ESTIMATED ANNUAL INVESTMENT DISBURSEMENTS
SCENARIO A - ONE DROP - 1000+1000 MW

YEAR	DISBURSEMENT YEARS	ANNUAL CASH FLOW (8 HOUR RESERVOIR) ($1000)	(PERCENT)	CUMULATIVE TOTAL ($1000)	(PERCENT)
1981	-8	24,457.0	4.2	24,457.0	4.2
1982	-7	19,867.5	3.4	44,324.5	7.6
1983	-6	31,362.0	5.4	75,686.5	13.0
1984	-5	26,217.0	4.5	101,903.5	17.5
1985	-4	57,822.0	9.9	159,725.5	27.4
1986	-3	83,503.5	14.3	243,229.0	41.8
1987	-2	117,284.5	20.1	360,513.5	61.9
1988	-1	112,995.5	19.4	473,509.0	81.3
1989	0	67,822.0	11.6	541,331.0	92.9
1990	1	41,124.0	7.1	582,455.0	100.0
TOTAL		582,455.0			

8

TABLE VIII-9

UNDERGROUND PUMPED STORAGE STUDY

ESTIMATED ANNUAL INVESTMENT DISBURSEMENTS

SCENARIO D - TWO DROP - 1000+1000 MW

YEAR/DISBURSEMENT	+Year	ANNUAL CASH FLOW: 6 HOUR RESERVOIR ($1000)	6 HOUR RESERVOIR (%)	8 HOUR RESERVOIR ($1000)	8 HOUR RESERVOIR (%)	10 HOUR RESERVOIR ($1000)	10 HOUR RESERVOIR (%)
1981	-8	25,211.0	4.6	25,211.0	4.2	25,211.0	3.8
1982	-7	21,722.0	3.9	21,722.0	3.6	21,722.0	3.3
1983	-6	33,933.0	6.2	33,933.0	5.6	33,933.0	5.2
1984	-5	25,494.0	4.6	25,494.0	4.2	25,494.0	3.9
1985	-4	48,654.5	8.8	48,654.5	8.1	48,654.5	7.4
1986	-3	57,747.0	10.5	75,747.0	12.5	93,747.0	14.2
1987	-2	108,927.0	19.8	126,927.0	21.0	144,927.0	22.0
1988	-1	114,597.5	20.8	132,597.5	21.9	150,597.5	22.9
1989	0	76,547.0	13.9	76,547.0	12.7	76,547.0	11.6
1990	+1	37,503.0	6.8	37,503.0	6.2	37,503.0	5.7
TOTAL		550,336.0		604,336.0		658,336.0	

TABLE VIII-10

ESTIMATED ANNUAL INVESTMENT DISBURSEMENTS FOUR 500MW COAL FIRED CYCLING UNITS

	1984	Start Construction 1989 Units	1985	Start Construction 1990 Units	1986	1987	1988	1989	1990
Disbursements - $\$10^6$ (January 1977 prices)	30		148		346	550	540	304	82
% Total	1.5		7.4		17.3	27.5	27.0	15.2	4.1
								TOTAL	2,000 1/
Present Worth Factor	1.203		1.160		1.117	1.077	1.038	1.000	0.964
Present Worth in 1989 including AFDC 2/	.36		172		386	590	560	304	79
								TOTAL	2,127

1/ $1,000/kW

2/ Cost of Money - 3.8%

for gas turbines (20 years). The annual final changes were taken for 50 years and then present-worthed to find the total investment cost in 1989. These figures are shown in Table VIII-11.

The 1989 present worth of the variable production costs of the alternatives was obtained by considering the cost to be frozen in the last year studied, 1990 for Scenario D, and 1992 for Scenario A. The resulting series of costs, added to the fixed operation and maintenance costs, and present-worthed to 1989, gave the total present worth of system operation over the 50 years of the study. These costs are also shown in Table VIII-11, as well as the total comparative present worth of each of the alternatives.

8.8 Sensitivity Analyses

The calculated comparative present worth costs of the alternative plans are directly dependent on original cost assumptions such as fuel prices, investment requirements and cost of money. A series of analyses were made to determine how sensitive the results are to a range of price variations. Because of the marginal economy of Scenario A, only Scenario D was studied.

First, coal price variations in a range of $0.45 per MBtu to $1.50/MBtu were studied. The study indicated that, as the coal price increases, the difference between the comparative present worths of UHPS and gas turbines decreases. This is due to the fact that the pumped storage pumping is done by the coal-fired units. Therefore, the pumped storage alternative is affected more than the gas turbine alternative by the variation of coal prices. However, the pumped storage alternative

TABLE VIII-11

UHPS STUDY

Alternative	1989 Present Worth ($ Millions)		
SCENARIO A	Investment[1]	Operation[2]	Total
UHPS Alternative	1003.9	50918.8	51922.7
Coal Fired Cycling Alternative	3795.1	50510.9	54306.0
Combustion Turbine Alternative	744.6	51187.1	51931.7
SCENARIO D			
UHPS 6 Hour Reservoir	952.2	34392.5	35344.7
UHPS 8 Hour Reservoir	1036.4	34338.4	35374.8
UHPS 10 Hour Reservoir	1120.6	34293.5	35414.1
Coal Fired Cycling Alternative	3795.1	33105.7	36900.8
Combustion Turbine Alternative	744.6	35266.8	36011.4

1/ Includes investment, taxes, insurance and fixed O&M, and interest during construction, for specific unit under consideration.

2/ Includes fuel cost and variable O&M for entire system under consideration.

remains more attractive than the coal fired cycling alternative for the entire range of coal prices because the coal fired cycling unit, with its higher plant factor, is more sensitive to coal prices. Table VIII-12 shows the comparative present worths of the alternatives with different coal prices.

Second, the effect of oil price variations were examined. Here, again, the pumped storage alternative clearly remained the most economical alternative for the oil price range of $1.50 per MBtu up to $3.00 per MBtu. Table VIII-13 shows the comparative present worths of the alternatives.

Third, the estimated investment of the underground pumped storage was changed to reflect possible cost increases due to inflation or unaccounted expenses associated with a transmission line or a particular site. The investment estimate of the pumped storage was therefore increased by 25 percent and then by 50 percent. The resulting comparative present worth figures are shown in Table VIII-14. The pumped storage alternative again remained the most economical alternative.

The final sensitivity analysis made was to express the total present worth cost savings of UHPS in terms of miles of EHV transmission, to give an indication of the possible flexibility in locating the UHPS site. Using typical values for costs of double circuit 500 kV transmission and an assumed life of 30 years, a curve was obtained which showed the 1989 present worth of transmission as a function of transmission mileage. Against this was plotted the savings in total present worth of the UHPS alternative over both the coal-fired cycling and gas turbine alternatives for each Scenario. The results are shown as Plates VIII-1 and VIII-2. They show that, in Scenario A, the advantage of UHPS over combustion turbines is small, equivalent

TABLE VIII-12

UHPS STUDY

SENSITIVITY OF UNDERGROUND HYDRO PUMPED STORAGE
TO VARIATIONS IN COST OF COAL

	Total Present Worth ($ Millions) at Cost of Coal of:		
Alternative	$ .45/MBtu	$1.00/MBtu	$1.50/MBtu
UHPS	26623.7	35344.7	43272.9
Coal Fired Cycling	27845.7	36900.8	45132.8
Gas Turbines	27607.5	36011.4	43651.4

8

TABLE VIII-13

UHPS STUDY

SENSITIVITY OF UNDERGROUND HYDRO PUMPED STORAGE
TO VARIATIONS IN COST OF OIL

	Total Present Worth ($ Millions) at Cost of Oil of:		
Alternative	$1.50/MBtu	$2.30/MBtu	$3.00/MBtu
UHPS	31180.3	35344.7	38988.6
Coal Fired Cycling	33389.7	36900.8	39973.1
Gas Turbines	31345.5	36011.4	40094.1

TABLE VIII-14

UHPS STUDY

SENSITIVITY OF UNDERGROUND HYDRO PUMPED STORAGE
TO VARIATIONS IN INVESTMENT

Alternative	Total Present Worth (Millions)
UHPS (Base Investment)	35344.7
UHPS (With 25% Increase in Investment)	35582.8
UHPS (With 50% Increase in Investment)	35820.8
Coal Fired Cycling	36900.8
Gas Turbines	36011.4

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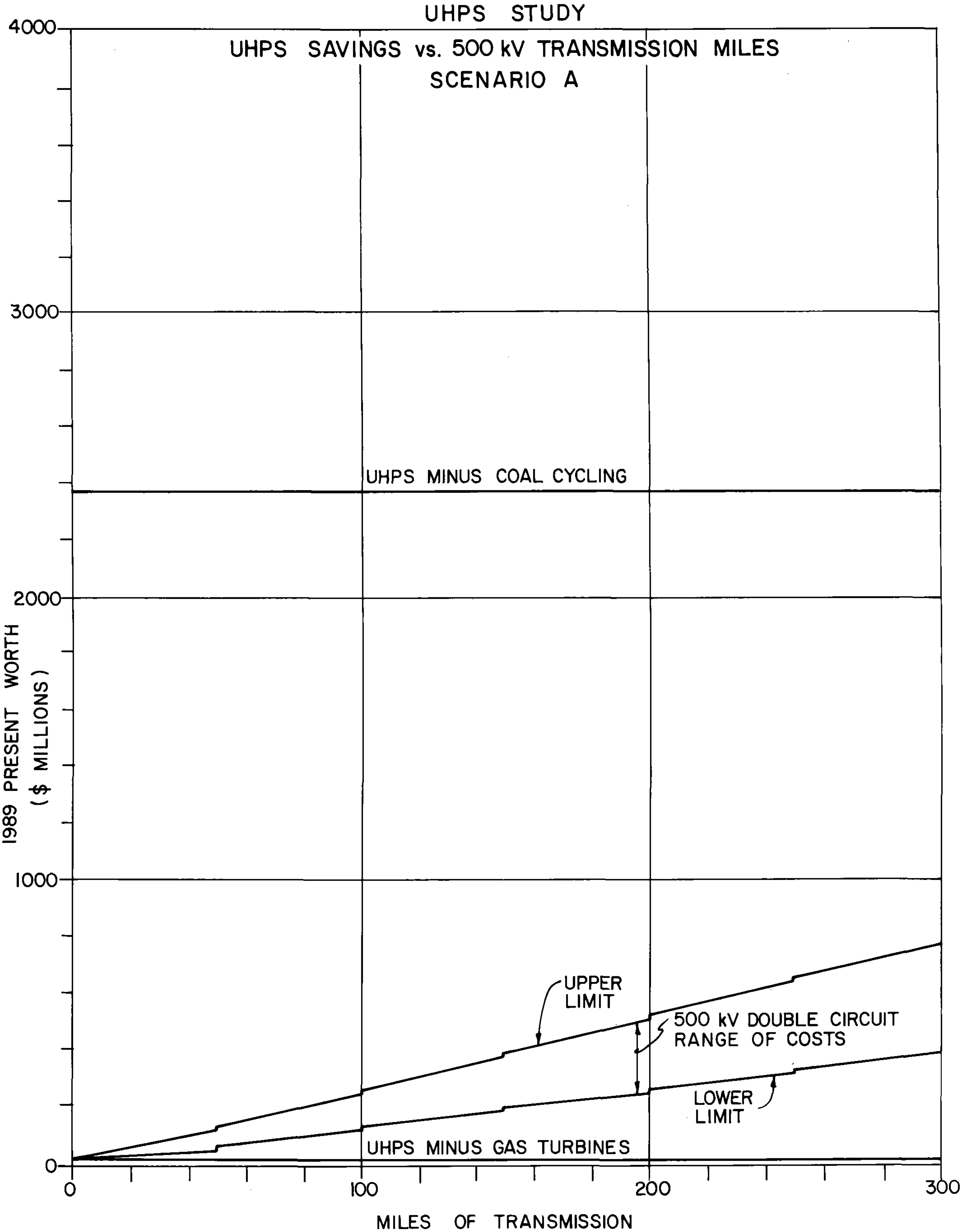
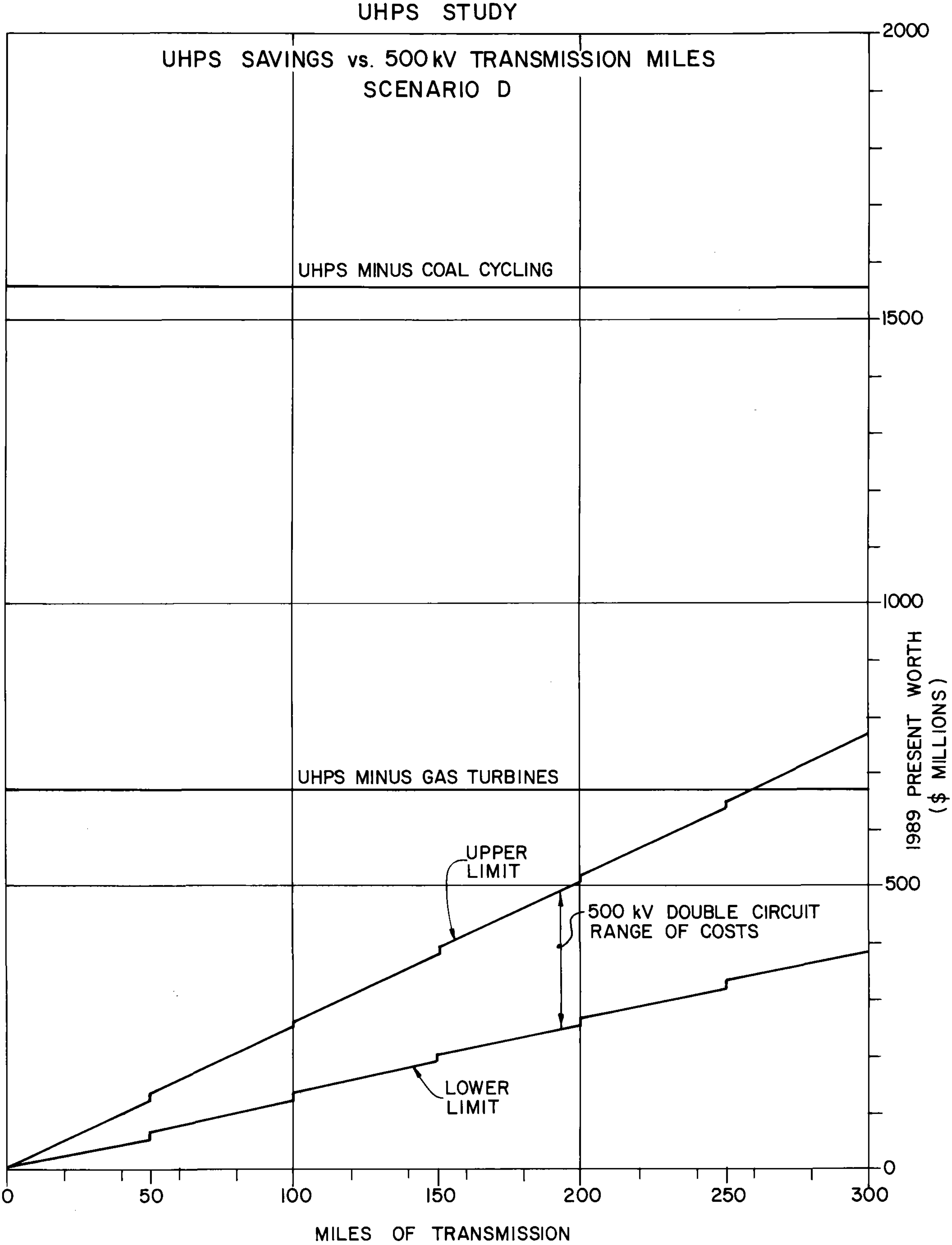


MAIN PLATE VIII - 1



MAIN PLATE VIII-2

to the cost of less than 10 miles of transmission, while the savings over coal-fired cycling units permits virtually unlimited flexibility in locating the UHPS site. In Scenario D, the savings over gas turbines are equivalent to the cost of more than 250 miles of transmission, and the savings over coal-fired cycling units again permits the location of the UHPS plant virtually anywhere on the power system.

It should be noted that these sensitivity analyses are only approximate. An actual change in the cost of coal or oil of more than a few percentage points will cause a change in the economic dispatching of the system generation in order to minimize the production costs. An exhaustive sensitivity analysis would re-calculate all system production costs at each different fuel cost. Such an analysis is beyond the scope of this study.

8.9 Results of System Analyses

An examination of the present worth costs of investment and system operation for the two Scenarios with alternative generation plans yields the following conclusions:

- In Scenario A, the UHPS alternative is the economic choice from among the three alternatives studied. It is, however, only marginally more economical than the gas turbines, due to the very low investment cost of the gas turbines. Because of the abundance of very efficient units in the system, there is not a large enough cost differential between base and peaking energy to permit the full utilization of the potential savings of UHPS. The coal-fired cycling units, on the other hand, reduce system operating costs greatly, largely because of their efficiency and the low cost of coal which allows them to operate at a plant factor of between 80 and 90 percent. The savings in production costs are not enough, however, to offset the higher investment cost and shorter plant life of the coal-fired cycling unit.

- In Scenario D, the economic analysis determines not only which alternative generation installation is most economical, but also which UHPS reservoir size provides the greatest overall economy for the life of the plant.

It is seen that the additional savings in production costs permitted by the 8 and 10 hour reservoirs are not enough to offset the increased investment cost of the larger reservoirs. This is largely due to the system load shapes which can only accommodate 6 hours of pumped storage in each daily cycle. Additional reservoir capacity can only be utilized on a weekly cycle. Six hours is therefore concluded to be the optimum reservoir size for the Scenario D system.

The generation mix in the Scenario D system is ideal for the operation of UHPS, consisting of sufficient baseload generation to permit weekend and weeknight pumping, with a significant amount of less efficient (or high fuel cost) units providing the peak requirements. The savings in fuel costs resulting from the operation of UHPS in this system outweigh the initial savings in the investment cost of gas turbines by a considerable amount.

The coal-fired cycling unit still results in lower fuel costs than pumped storage due to its higher plant factor. The savings are not enough to justify the higher investment cost of this alternative, however.

8.10 Optimum Storage

For the Scenario "D" study with incremental storage costing $14/kWH (Plate III-9), and charging energy cost for pumping (as scheduled in Appendix D - Chapter 8 at costs shown in Table VIII-4) at 10 mils/kWH, Table VIII-11 shows that 6 hour storage is more economical than 8 and 10 hour storage.

Note that the present worth of two hours storage in Table VIII-11 is $83,000,000 (for 4,000,000 kWH storage or $21.5. The difference between $21.5 and $14 is accounted for by interest, taxes, insurance and sinking fund requirements as indicated on page 8-20.

Refer to Table VIII-11 for the following analysis:

If incremental storage could be built for $9/kWH ($14 x 54 ÷ 84) = ($14 x investment difference between 6 and 8 hour reservoir ÷ by same difference for operation) 8 hour storage would be more economical than 6 hour; and if additional storage for less than $7/kWH, 10 hour storage would be most economical.

If all other factors but charging energy cost remained as depicted in Table VIII-11, optimum storage would be determined as follows:

1. With pumping costs at approximately 10 mils/kWH

UHPS Reservoir	APPROXIMATE AVERAGE ANNUAL PUMPING MWH	$	Δ $
6 Hour	3,260,000	32,600,000	
8 Hour	3,520,000	35,200,000	2,600,000
10 Hour	3,780,000	37,800,000	2,600,000

Present worth (at 3.8 interest) of a series of 50 annual pumping cost differences of $2,600,000 involves a multiplier of 22.2 and is thus $57,600,000.

2. To justify 8 hour vs. 6 hour storage requires an additional operation saving of 85-54 = $30,000,000 (present worth). Lower charging or pumping cost (unit) of (57.6-30)/57.6 x 10 mils = 5 mils/KWH would be necessary.

3. Similarly to justify 10 hour storage a charging cost of 3.4 mils/kWH is needed.

As demonstrated in this chapter no short-cut solution to the optimization of the amount of energy storage to be provided with UHPS plant of given capacity is possible. System studies as summarized in Table VIII-11 are necessary to provide the data for realistic economic analysis.

8

8.11 Conclusions

A comparison of the results of the economic analysis of each system shows that UHPS is the most economical alternative in both systems studied.

In the Scenario A system, the economy of UHPS is only marginal, whereas in the Scenario D system the economy of UHPS is large. The difference is the cost of energy displaced by pumped storage generation at the load peak. In Scenario A, this energy is ordinarily supplied by a mixture of oil-fired units and coal-fired units. In Scenario D, this peak energy is supplied entirely by oil-fired capacity. Because the cost of coal assumed, $1.00/MBtu, is so much lower than the cost of oil, $2.30/MBtu, the average cost of the peak energy is considerably lower in Scenario A than it is in Scenario D, resulting in a corresponding decrease in the economy of pumped storage operation. Any decrease in the price differential of coal and oil, however, serves to decrease the operating economy of pumped storage, since its economy lies in its ability to displace a more expensive fuel (oil) with a less expensive fuel (coal).

APPENDICES

(Simulated Power Systems Analyses)

8

Note: The appendices herein are taken from:

"Synthetic Electric Utility Systems for Evaluating Advanced Technologies" - EPRI EM-285, Electric Power Research Institute

APPENDIX A

8

SCENARIO A GENERATION CHARACTERISTICS

Full Scenario A

System Size: 53,350 MW
Total Number of Units: 241

Quantity	Unit Size (MW)	Unit Description
5	1200	Nuclear, steam
5	1000	Nuclear, steam
3	800	Coal, fossil
17	600	Coal, fossil
14	400	Coal, fossil
7	400	Oil, fossil
67	200	Coal, fossil
7	200	Oil, fossil
5	200	PS, hydro
12	50	Coal, fossil
87	50	Comb. turbines
12	50	Hydro

Mix of Unit Type (% Capacity)	Mix of Unit Size (% Capacity)
60% Coal, fossil	25% 700 MW +
21% Nuclear, steam	35% 300-700 MW
8% Oil, fossil	30% 60-300 MW
8% Comb. turbines	10% 0-60 MW
2% PS, hydro	
1% Hydro	

Scaled Down Power Production Scenario A

System Size: 10,675 MW
Number of Units to Dispatch: 48

Quantity	Unit Size (MW)	Unit Description
1	1200	Nuclear, steam
1	1000	Nuclear, steam
4	600	Coal, fossil
3	400	Coal, fossil
1	400	Oil, fossil
13	200	Coal, fossil
2	200	Oil, fossil
4	50	Coal, fossil
19	50	Comb. turbines
-	200	PS, hydro
-	125	Hydro

Mix of Unit Type (% Capacity)

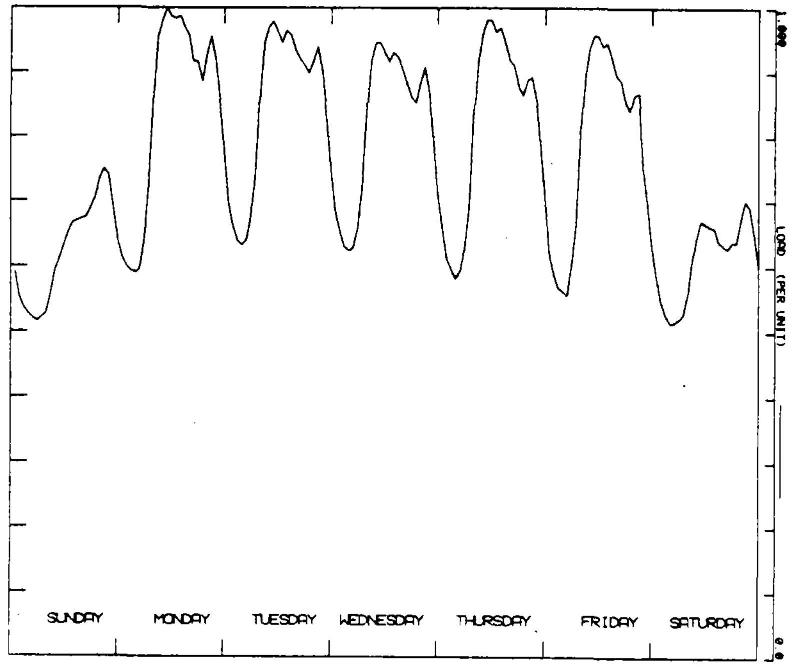
60% Coal, fossil
21% Nuclear, steam
7% Oil, fossil
9% Comb. turbines
2% PS, hydro
1% Hydro

SCENARIO A MONTHLY PEAK DATA

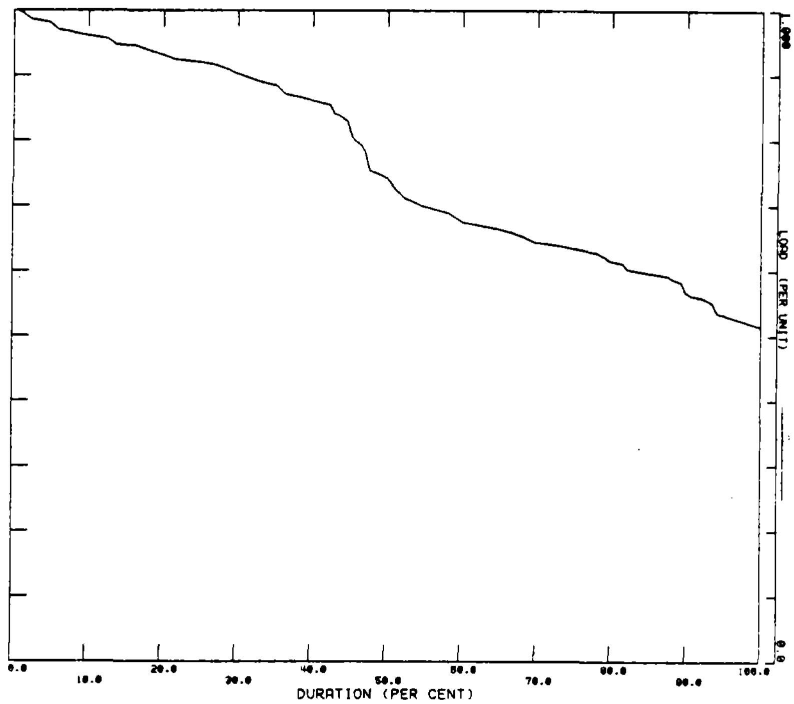
Month	Monthly Peak (P.U. Annual Peak)	Corresponding Load Duration Curve Season	Corresponding Load Duration Curve Load Factor (%)
January	.78	Winter	78
February	.76	Winter	78
March	.72	Spring/Fall	76
April	.70	Spring/Fall	76
May	.76	Summer	69
June	.93	Summer	69
July	.98	Summer	69
August	1.00	Summer	69
September	.90	Summer	69
October	.74	Spring/Fall	76
November	.78	Spring/Fall	76
December	.80	Winter	78

Approximate Annual Load Factor 59%

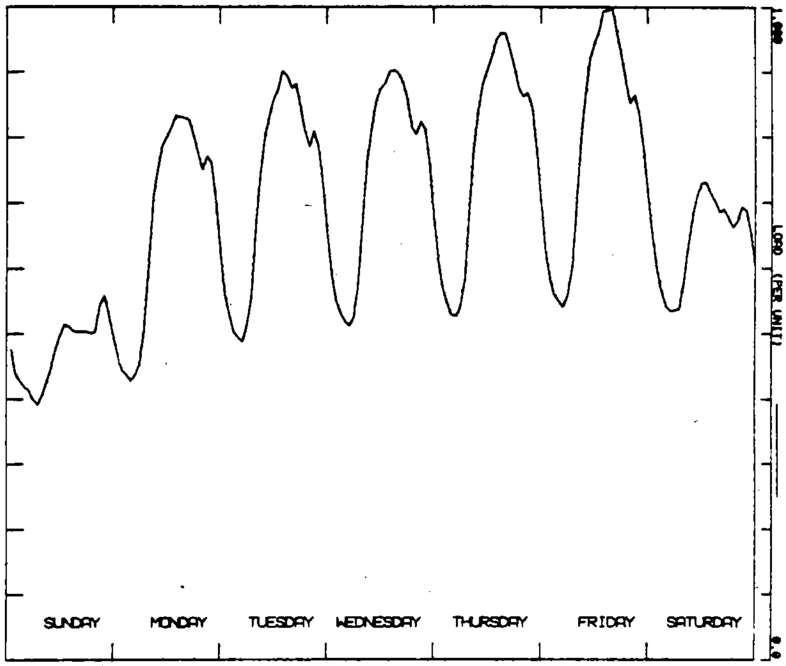
8



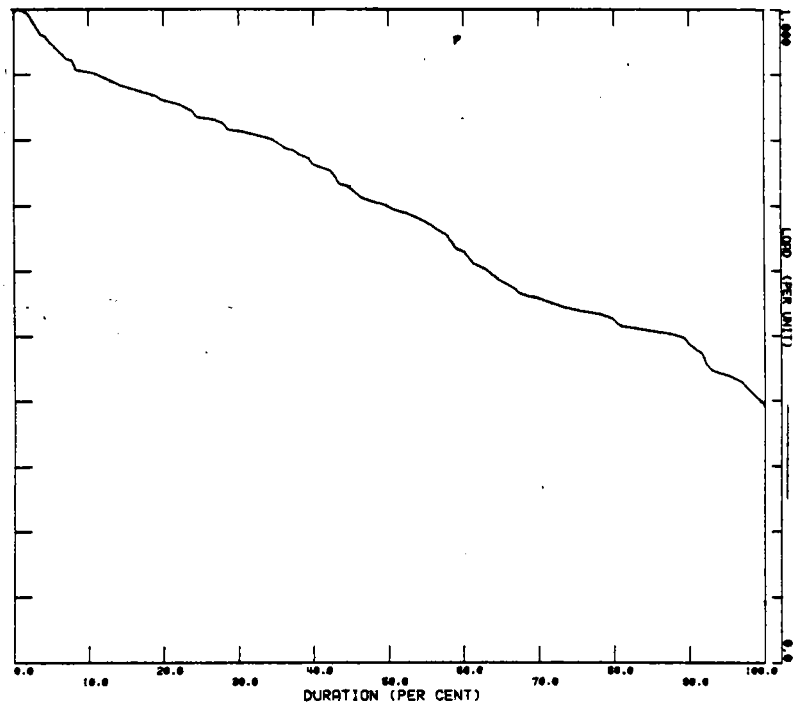
Scenario A - Spring/Fall Weekly Load Cycle Plot



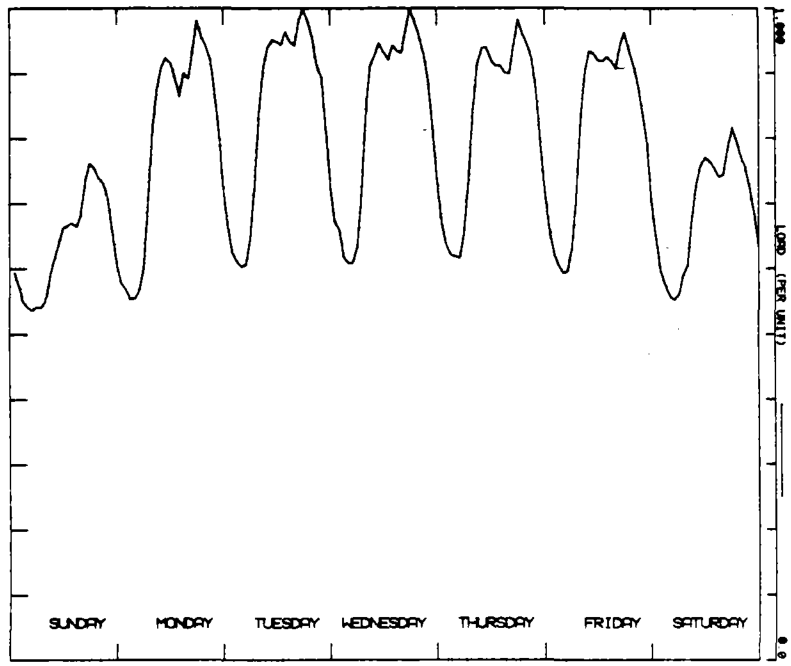
Scenario A - Spring/Fall Load Duration Curve



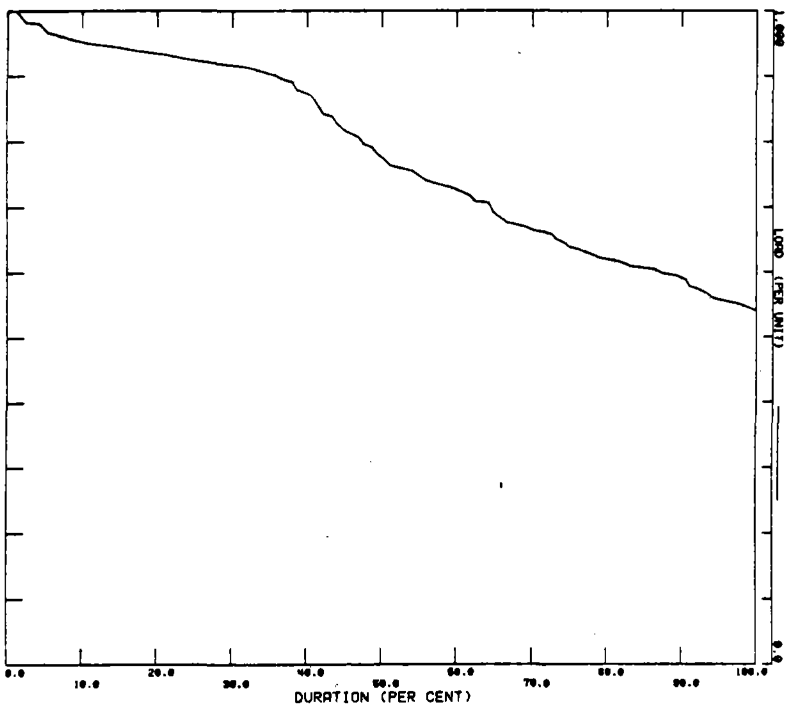
Scenario A - Summer Weekly Load Cycle Plot



Scenario A - Summer Load Duration Curve



Scenario A - Winter Weekly Load Cycle Plot



Scenario A - Winter Load Duration Curve

APPENDIX B

8

SCENARIO D GENERATION CHARACTERISTICS

Full Scenario D

System Size: 32,000 MW
Total Number of Units: 174

Quantity	Unit Size (MW)	Unit Description
6	1200	Nuclear, steam
1	800	Nuclear, steam
1	800	Coal, fossil
1	800	Oil, fossil
3	600	Coal, fossil
3	600	Oil, fossil
5	400	Coal, fossil
2	400	Oil, fossil
33	200	Coal, fossil
23	200	Oil, fossil
96	50	Comb. turbines

Mix of Unit Type (% Capacity)	Mix of Unit Size (% Capacity)
25% Oil, fossil	30% 700 MW +
15% Comb. turbines	20% 300-700 MW
35% Coal, fossil	35% 60-300 MW
25% Nuclear, steam	15% 0-60 MW

Scaled Down Power Production Scenario D

System Size: 10,050 MW
Number of Units to Dispatch: 54

Quantity	Unit Size (MW)	Unit Description
2	1200	Nuclear, steam
1	800	Oil, fossil
2	600	Coal, fossil
2	400	Coal, fossil
1	400	Oil, fossil
8	200	Coal, fossil
7	200	Oil, fossil
29	50	Comb. turbines

Mix of Unit Type (% Capacity)
26% Oil, fossil
14% Comb. turbines
36% Coal, fossil
24% Nuclear, steam

SCENARIO D MONTHLY PEAK DATA

Month	Monthly Peak (P.U. Annual Peak)	Corresponding Load Duration Curve Season	Load Factor (%)
January	.75	Winter	78
February	.72	Winter	78
March	.71	Spring/Fall	74
April	.68	Spring/Fall	74
May	.72	Spring/Fall	74
June	.93	Summer	73
July	1.00	Summer	73
August	.95	Summer	73
September	.82	Spring/Fall	74
October	.73	Spring/Fall	74
November	.75	Spring/Fall	74
December	.78	Winter	78

Approximate Annual Load Factor 59%

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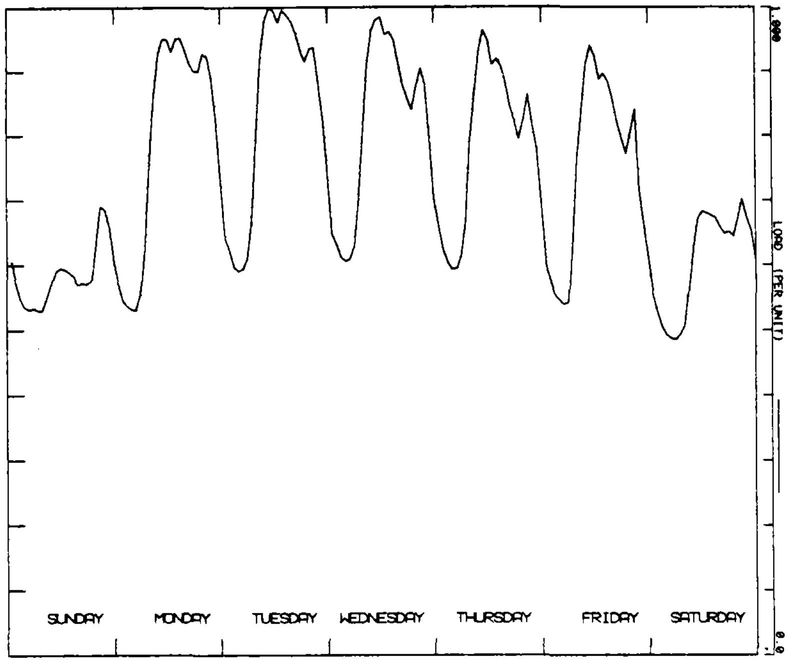
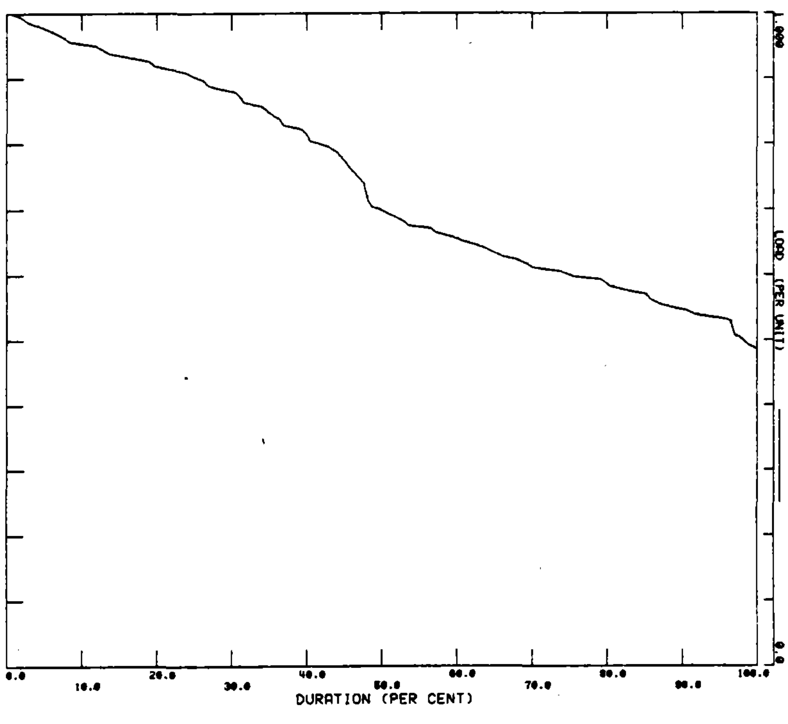
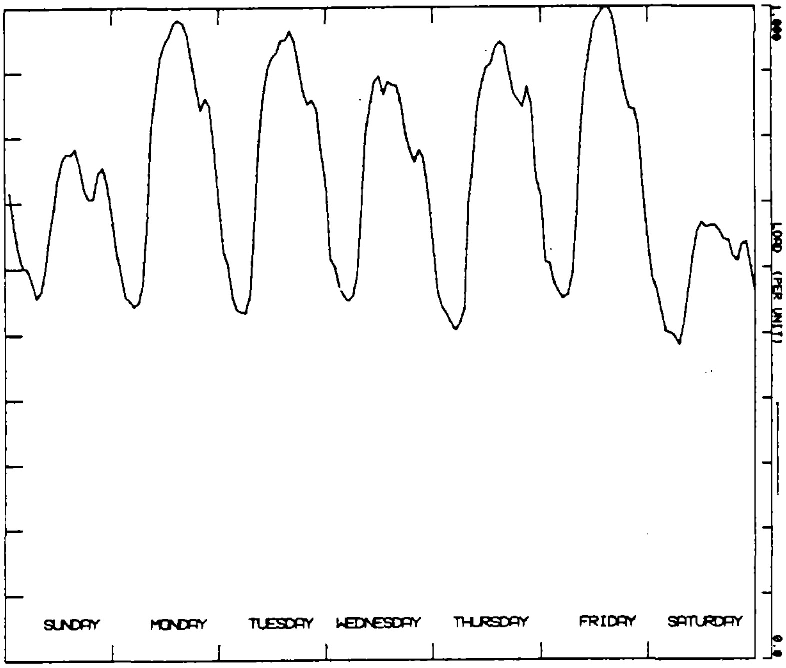


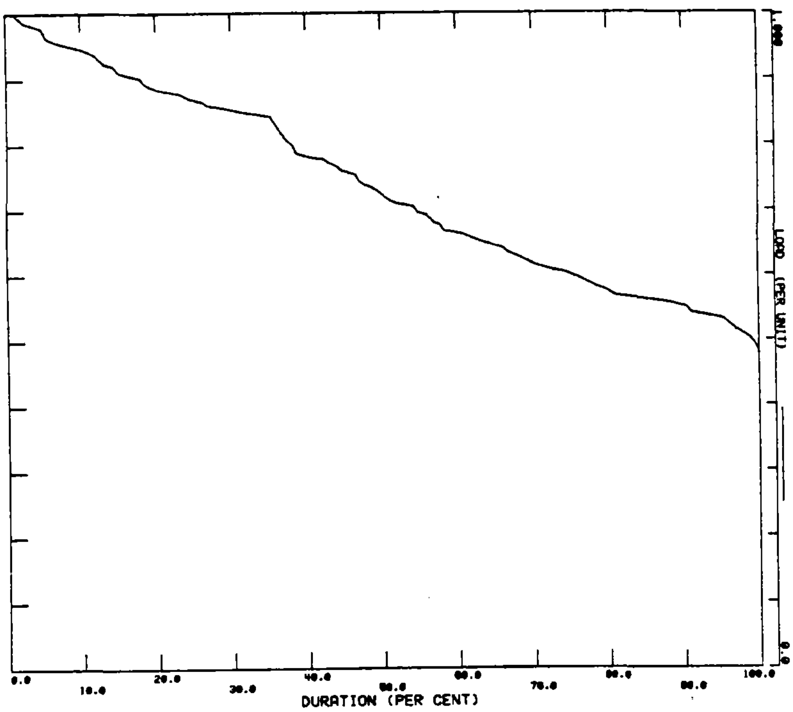
Scenario D - Spring/Fall Weekly Load Cycle Plot



Scenario D - Spring/Fall Load Duration Curve



Scenario D - Summer Weekly Load Cycle Plot



Scenario D - Summer Load Duration Curve

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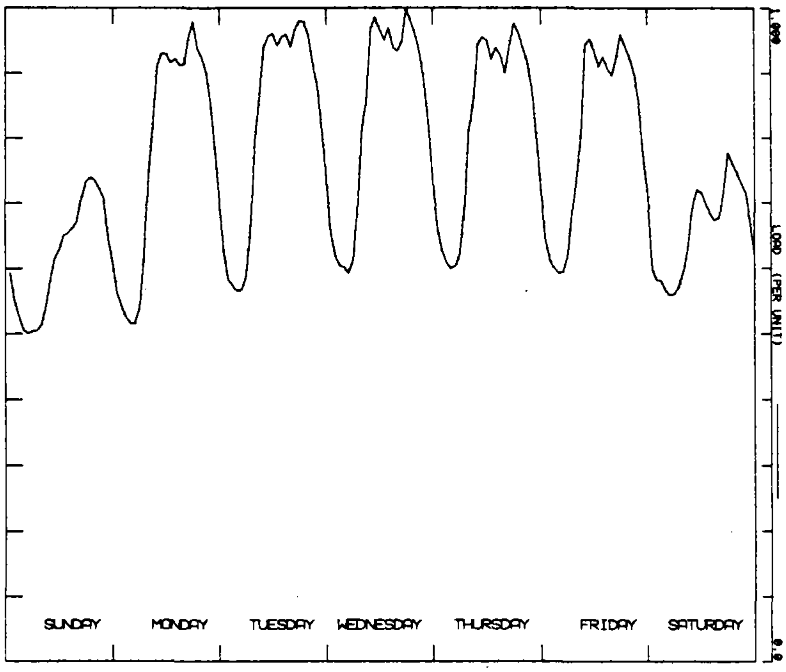
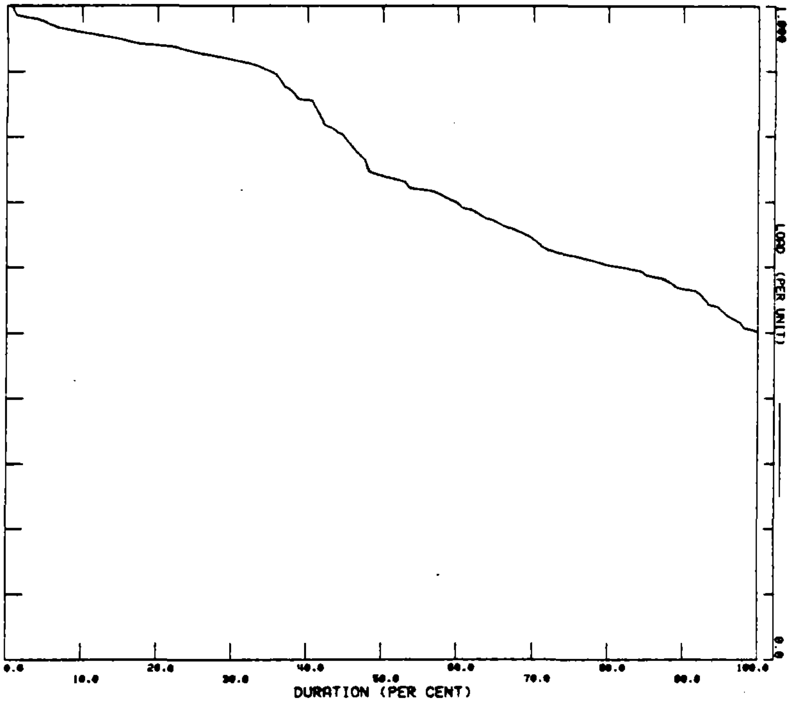


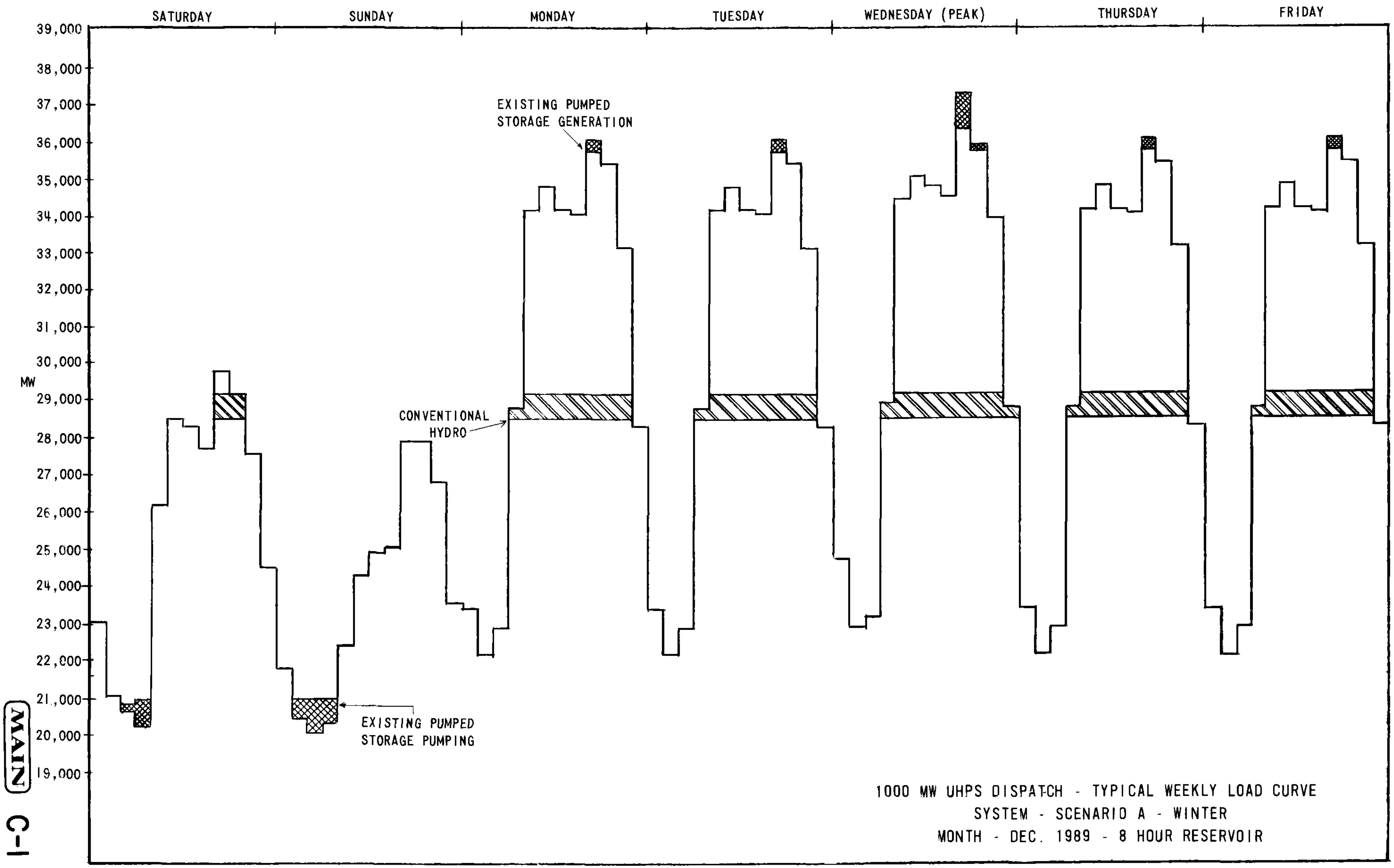
Scenario D - Winter Weekly Load Cycle Plot



Scenario D - Winter Load Duration Curve

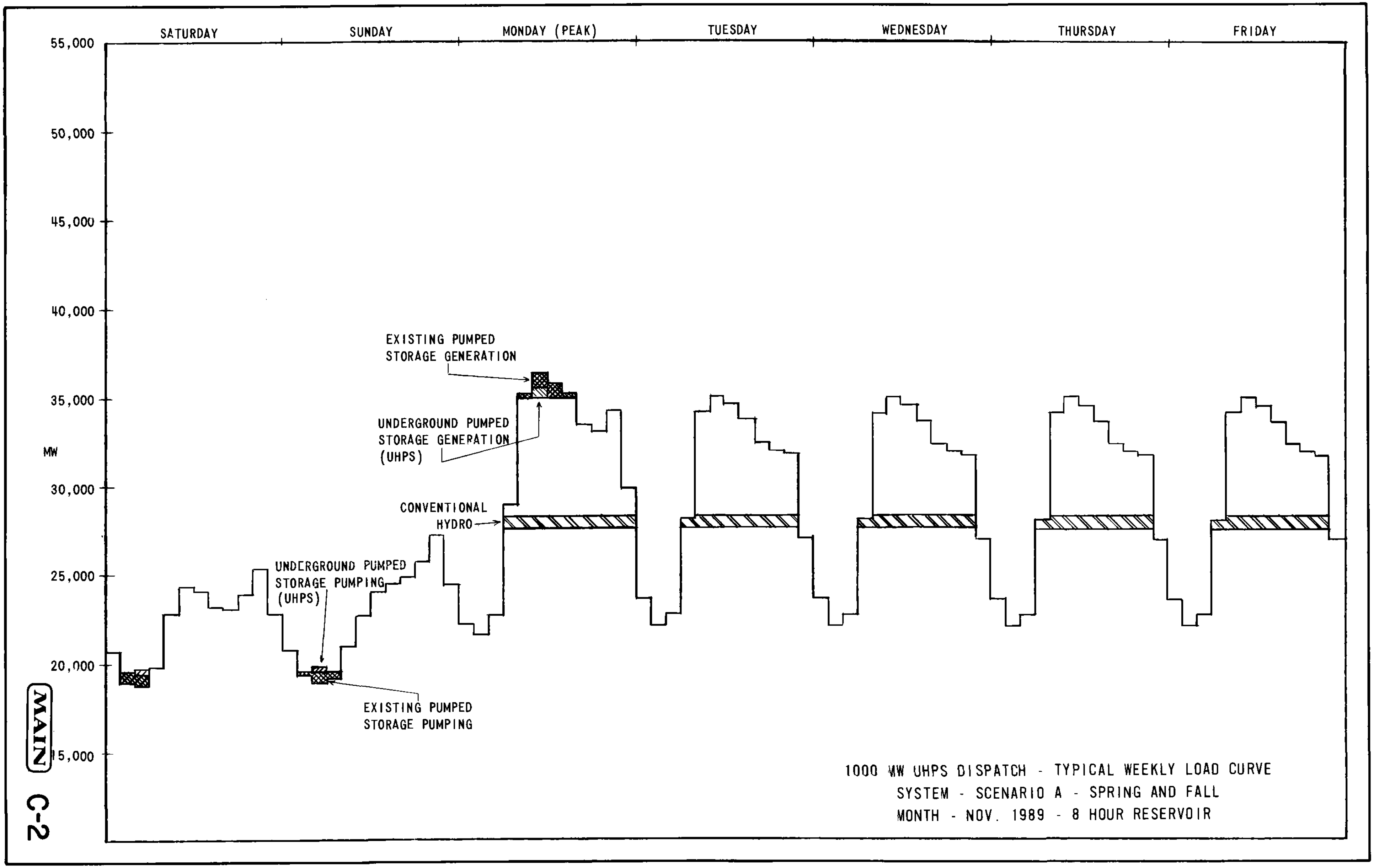
APPENDIX C

8


SATURDAY
SUNDAY
MONDAY
TUESDAY
WEDNESDAY (PEAK)
THURSDAY
FRIDAY
MW
39,000
38,000
37,000
36,000
35,000
34,000
33,000
32,000
31,000
30,000
29,000
28,000
27,000
26,000
25,000
24,000
23,000
22,000
21,000
20,000
19,000
EXISTING PUMPED STORAGE GENERATION
CONVENTIONAL HYDRO
EXISTING PUMPED STORAGE PUMPING
1000 MW UHPS DISPATCH - TYPICAL WEEKLY LOAD CURVE
SYSTEM - SCENARIO A - WINTER
MONTH - DEC. 1989 - 8 HOUR RESERVOIR

MAIN

C-1


SATURDAY
SUNDAY
MONDAY (PEAK)
TUESDAY
WEDNESDAY
THURSDAY
FRIDAY
55,000
50,000
45,000
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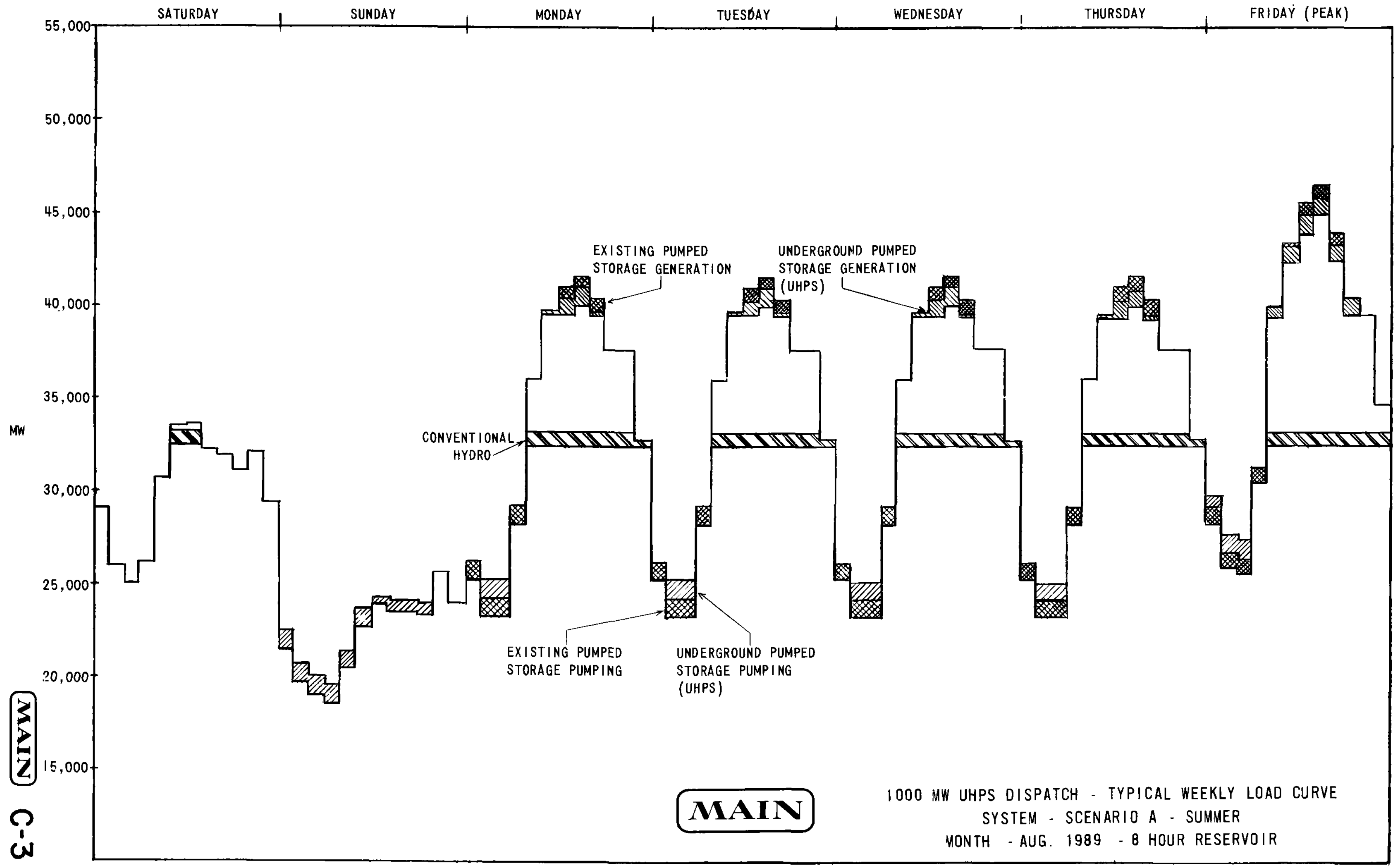
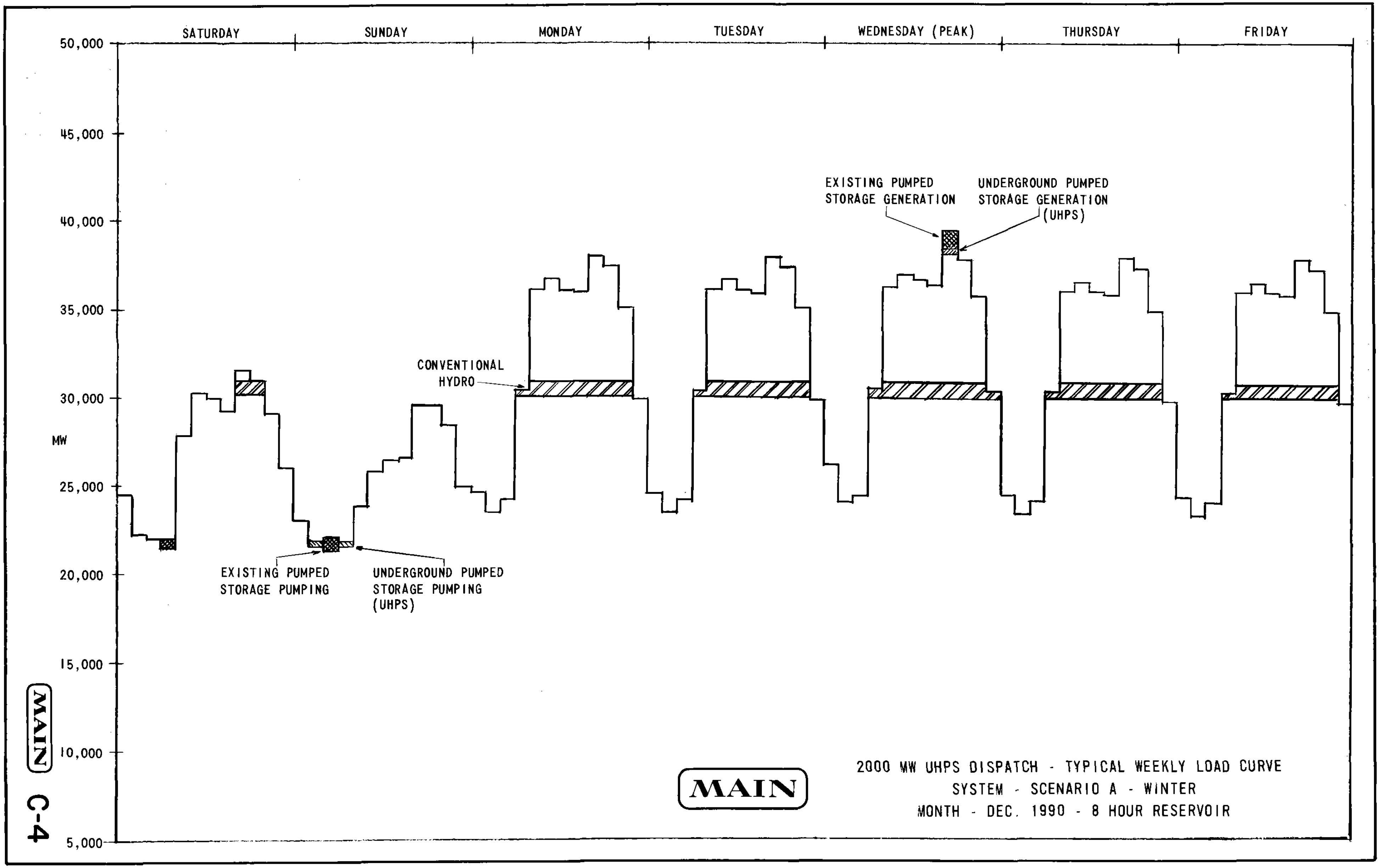
MW
EXISTING PUMPED STORAGE GENERATION
UNDERGROUND PUMPED STORAGE GENERATION (UHPS)
CONVENTIONAL HYDRO
UNDERGROUND PUMPED STORAGE PUMPING (UHPS)
EXISTING PUMPED STORAGE PUMPING
1000 MW UHPS DISPATCH - TYPICAL WEEKLY LOAD CURVE
SYSTEM - SCENARIO A - SPRING AND FALL
MONTH - NOV. 1989 - 8 HOUR RESERVOIR
MAIN
C-2



1000 MW UHPS DISPATCH - TYPICAL WEEKLY LOAD CURVE
SYSTEM - SCENARIO A - SUMMER
MONTH - AUG. 1989 - 8 HOUR RESERVOIR

MAIN C-3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WEDNESDAY (PEAK)
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MW
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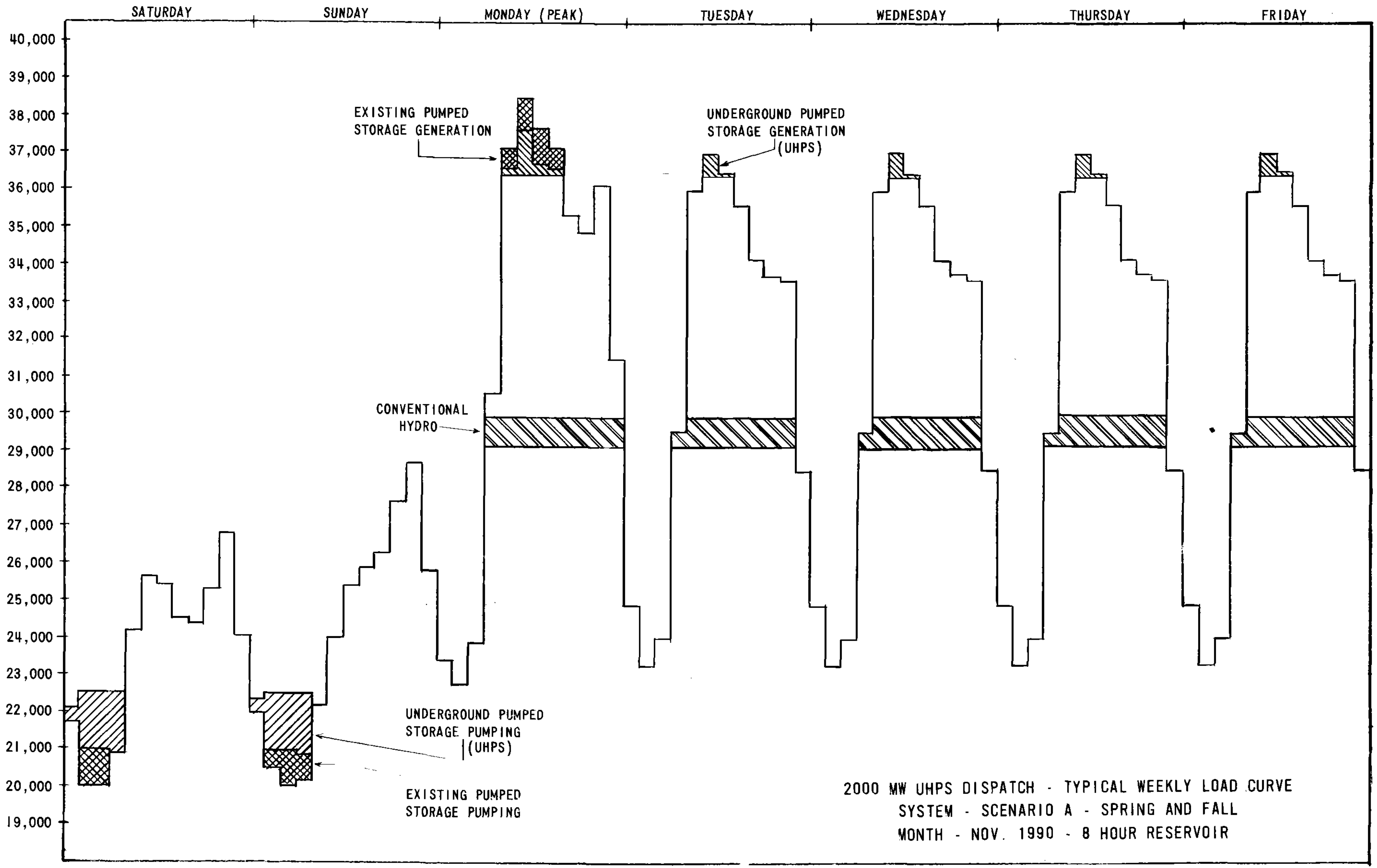
5,000
EXISTING PUMPED STORAGE GENERATION
UNDERGROUND PUMPED STORAGE GENERATION (UHPS)
CONVENTIONAL HYDRO
EXISTING PUMPED STORAGE PUMPING
UNDERGROUND PUMPED STORAGE PUMPING (UHPS)
MAIN
2000 MW UHPS DISPATCH - TYPICAL WEEKLY LOAD CURVE
SYSTEM - SCENARIO A - WINTER
MONTH - DEC. 1990 - 8 HOUR RESERVOIR
MAIN
C-4

MAIN C-5


SATURDAY
SUNDAY
MONDAY (PEAK)
TUESDAY
WEDNESDAY
THURSDAY
FRIDAY
MW
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39,000
38,000
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36,000
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34,000
33,000
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28,000
27,000
26,000
25,000
24,000
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22,000
21,000
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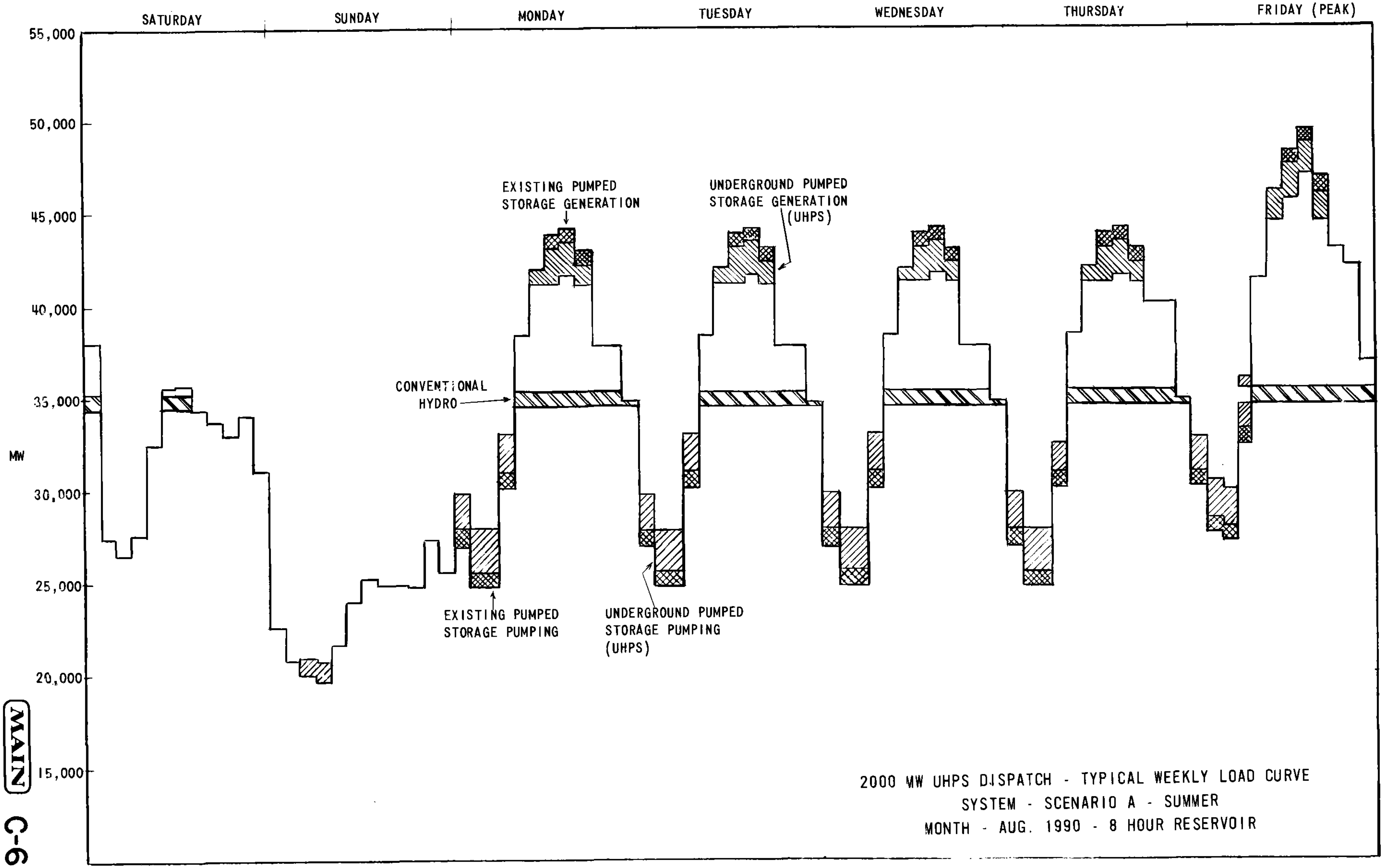
19,000
EXISTING PUMPED STORAGE GENERATION
UNDERGROUND PUMPED STORAGE GENERATION (UHPS)
CONVENTIONAL HYDRO
UNDERGROUND PUMPED STORAGE PUMPING (UHPS)
EXISTING PUMPED STORAGE PUMPING
2000 MW UHPS DISPATCH - TYPICAL WEEKLY LOAD CURVE
SYSTEM - SCENARIO A - SPRING AND FALL
MONTH - NOV. 1990 - 8 HOUR RESERVOIR

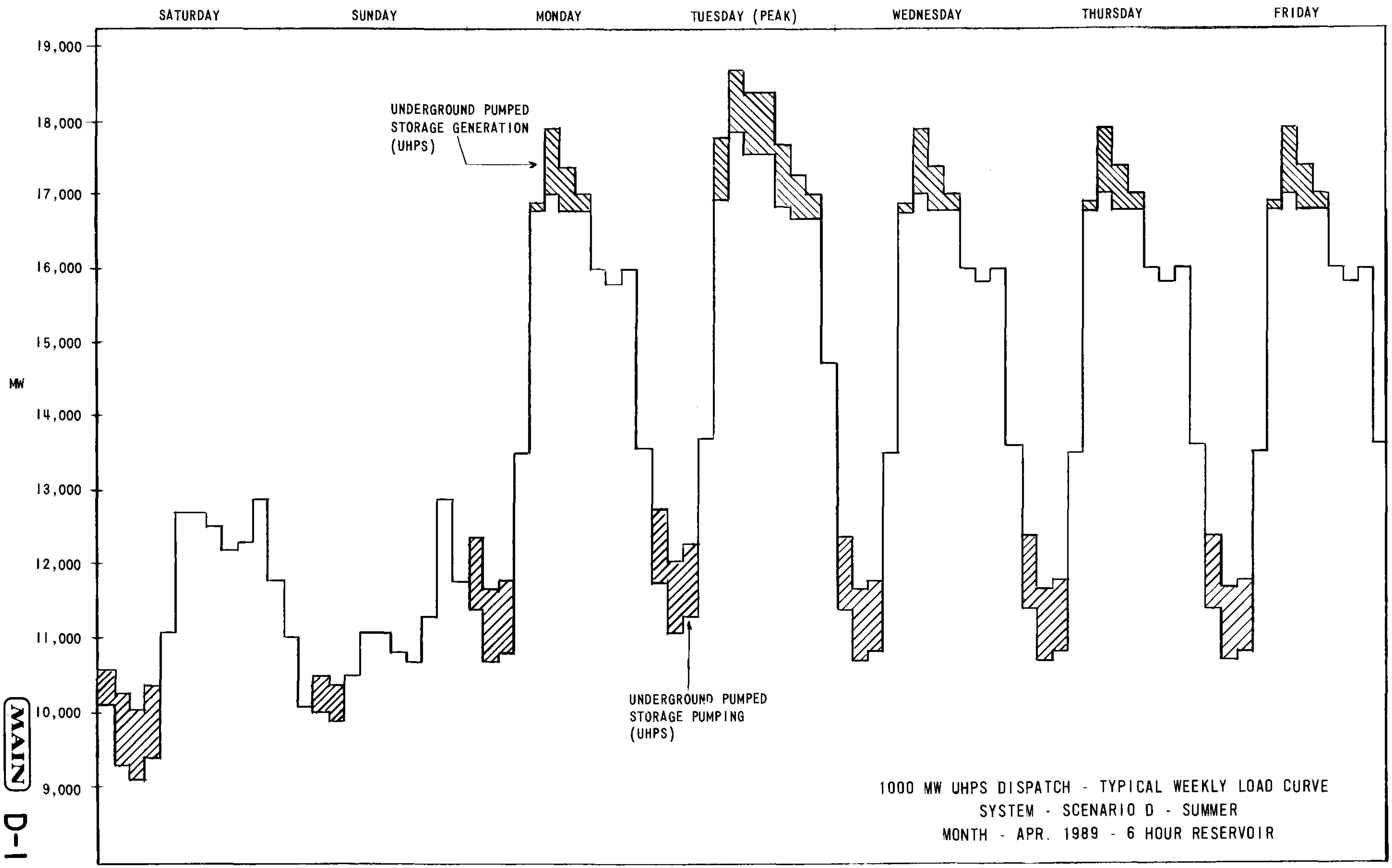


2000 MW UHPS DISPATCH - TYPICAL WEEKLY LOAD CURVE
SYSTEM - SCENARIO A - SUMMER
MONTH - AUG. 1990 - 8 HOUR RESERVOIR

MAIN C-6

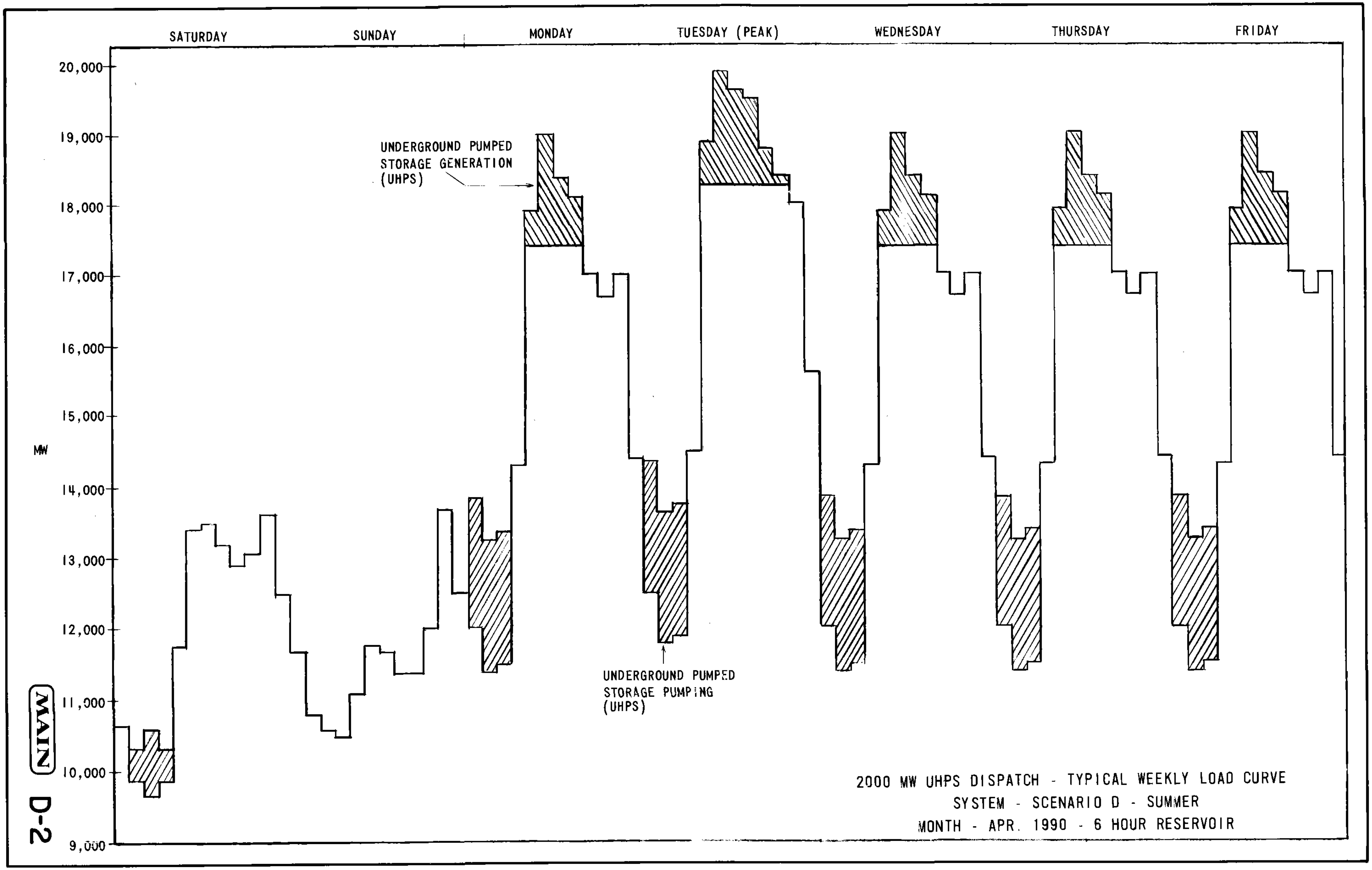
APPENDIX D

8



1000 MW UHPS DISPATCH - TYPICAL WEEKLY LOAD CURVE
SYSTEM - SCENARIO D - SUMMER
MONTH - APR. 1989 - 6 HOUR RESERVOIR

MAIN D-1



SATURDAY
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TUESDAY (PEAK)
WEDNESDAY
THURSDAY
FRIDAY
20,000
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16,000
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MW
14,000
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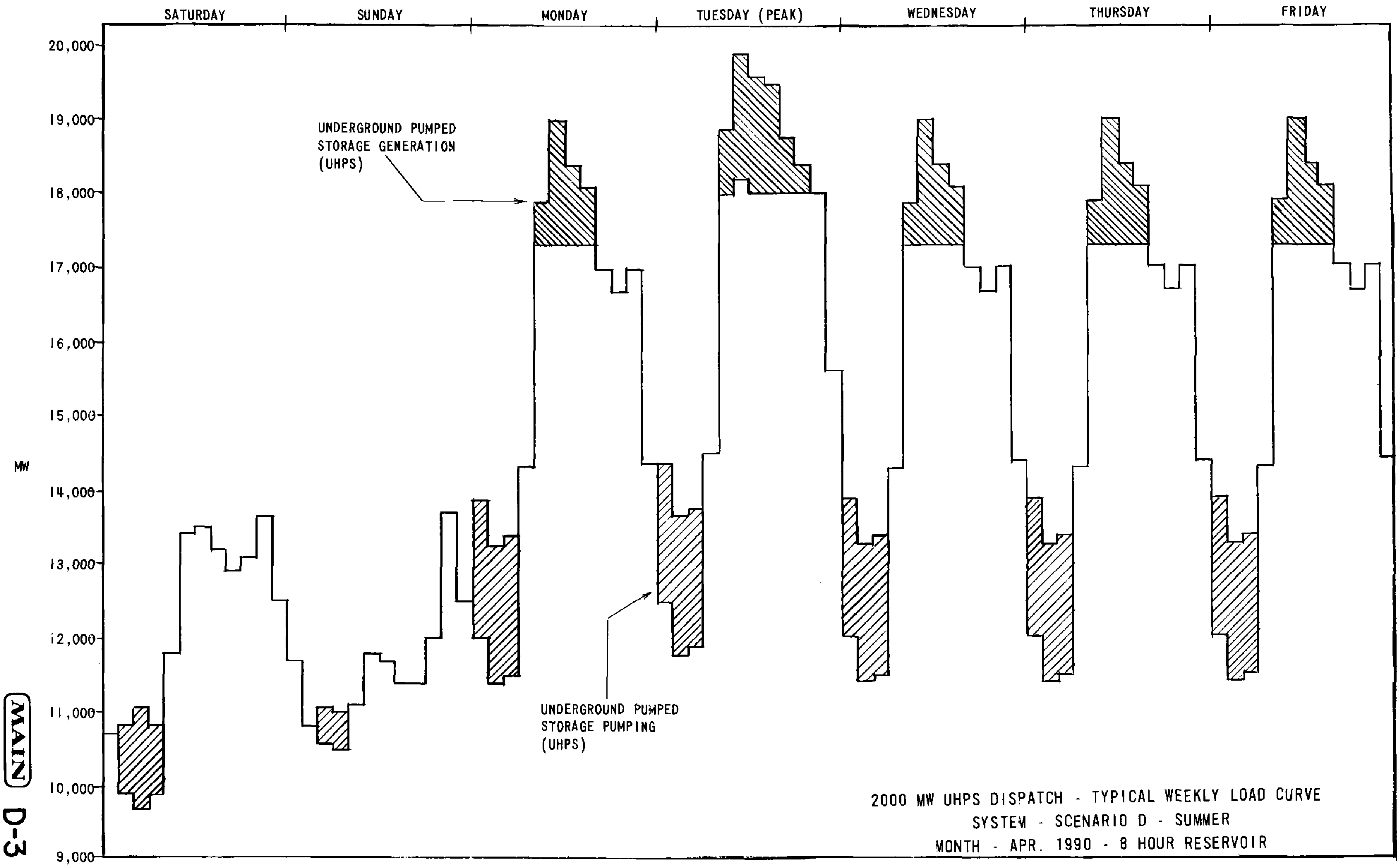
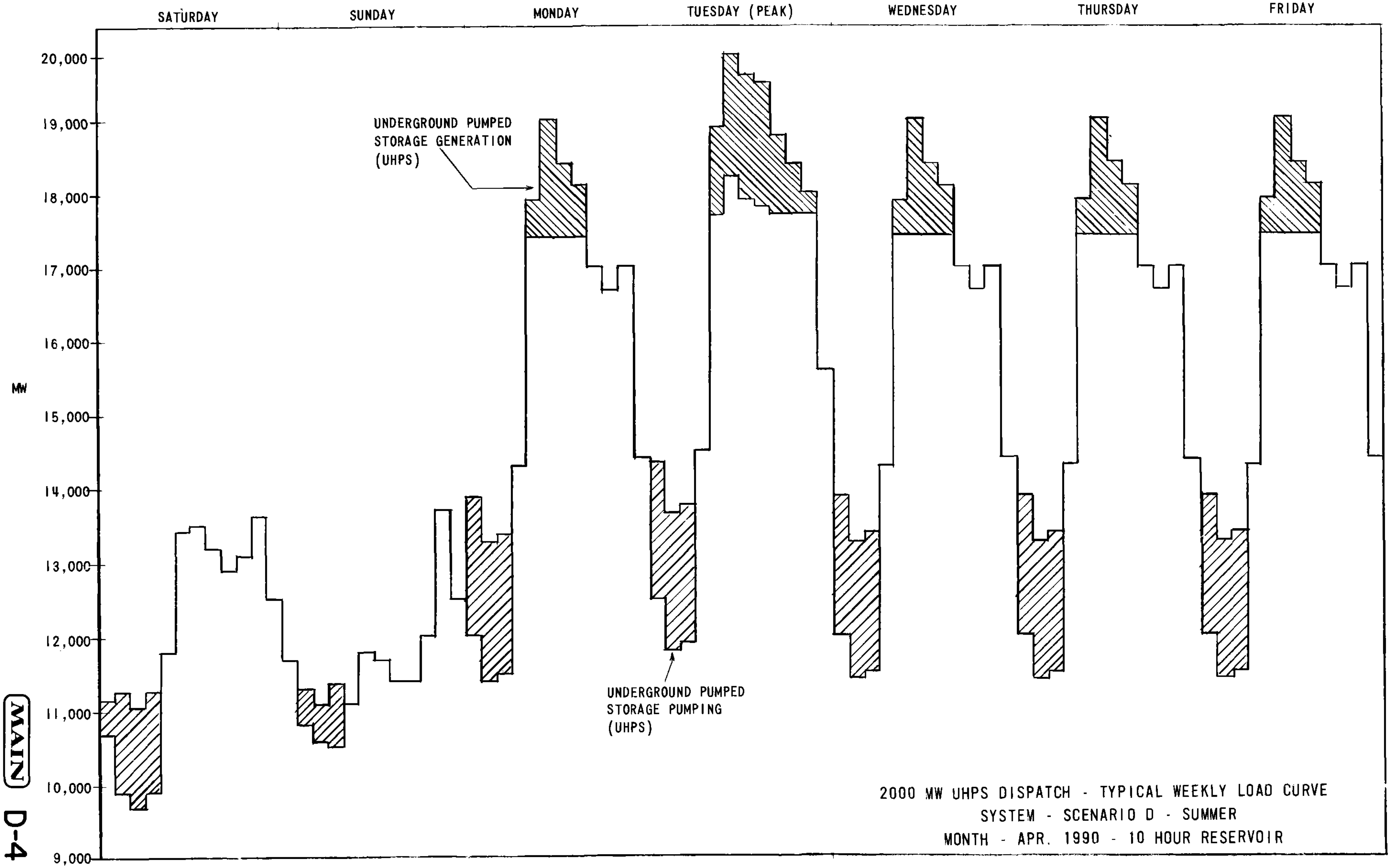
11,000
10,000
9,000
UNDERGROUND PUMPED STORAGE GENERATION (UHPS)
UNDERGROUND PUMPED STORAGE PUMPING (UHPS)
2000 MW UHPS DISPATCH - TYPICAL WEEKLY LOAD CURVE
SYSTEM - SCENARIO D - SUMMER
MONTH - APR. 1990 - 6 HOUR RESERVOIR

MAIN D-2



2000 MW UHPS DISPATCH - TYPICAL WEEKLY LOAD CURVE
SYSTEM - SCENARIO D - SUMMER
MONTH - APR. 1990 - 8 HOUR RESERVOIR

MAIN D-3



2000 MW UHPS DISPATCH - TYPICAL WEEKLY LOAD CURVE
SYSTEM - SCENARIO D - SUMMER
MONTH - APR. 1990 - 10 HOUR RESERVOIR

MAIN D-4

9.0 ECONOMICS OF UNDERGROUND HYDROELECTRIC PUMPED STORAGE

9.1 General

Pumped storage is not, in itself, a self-initiator in the generation mix, but rather a form of energy storage. It depends on an outside energy source to raise water from the lower reservoir to the upper reservoir to develop an operating head. The same principle is applicable to UHPS and conventional pumped storage. The pumping energy is obtained from base load units, thermal or economically preferable nuclear, during periods of reduced demand....weekends and early morning hours. It is acknowledged that it takes approximately three (3) kWh of base energy to produce two (2) of energy from pumped storage. However, this latter form of energy is prime peak energy which has a far greater pricing value and greater financial return. During peak load periods, energy is taken from storage, thus reducing or eliminating the operation of less efficient units operating with premium fuels.

Studies by the Public Service Electric and Gas Company of New Jersey (Study No. 2, Table II-1) indicate a definite market for economical energy storage schemes and found that hydro pumped storage is more attractive than any other storage form. This includes thermal, oil and steam storage, compressed air, battery storage lead acid, hydrogen, flywheel, and superconducting magnetic energy storage.

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9.2 Electric System Variables

9.2.1 Load and Generation Characteristics

The economic feasibility of UHPS is dictated by the character of the load and the available generation. There is a general uniformity, to date, in load shapes throughout the United States - daily, weekly and seasonal, and no particular region seems to have load characteristics more conducive to UHPS than any other. The particular generation mix in a given electric system governs the marketability of UHPS.

The studies reported herein demonstrate that UHPS is most appropriate in systems where its presence enables a substantial reduction in costly combustion turbine operation. Such is the case in systems having normal reserve (20 to 25%) with about 15% combustion turbines and 8% pumped storage. In systems having normal reserve with combustion turbine capacity less than 10%, there is little call on the combustion turbines and thus marginal justification, at best, for UHPS, whose estimated initial cost is substantially higher than that of combustion turbines.

9.2.2 Transmission

The economic feasibility of a particular UHPS project may be determined by the transmission credit or penalty associated with the project. As an electric system grows in capacity, its associated transmission grid grows apace. The location of surface hydroelectric projects (pumped storage or standard) are typically determined by topographic factors which overrule transmission considerations. UHPS, with no rigid topographic constraints, offers greater opportunities to avoid transmission penalties. To judge the order of magnitude of possible transmission credits or penalties associated with a 2000 MW UHPS project, it is noted that, at January 1977 prices, assuming three 345 kV circuits at $225,000 per circuit mile (Ref. 10, Table II-2), the cost per mile of transmission would be equivalent to $0.34/kW. One hundred (100) miles of transmission would thus cost $34/kW (or approximately 10% of the UHPS plant cost).

9.3 Comparative Hydropower Costs

The cost of hydropower fluctuates widely, depending on size or capacity, site conditions, and environmental influences and impacts. Since conventional hydroelectric power is dependent on flowing water and seasonal stream stages, it has not been considered a viable UHPS alternative in this report. This negativity can, in instances, carry over to typical conventional hydroelectric pumped storage.

Based on the per kilowatt costs of Schemes I through III of this report, ranging from $318 to $347, UHPS with 10-hour storage is competitive with large conventional pumped storage (when a lower reservoir is not already existing). The Bath County Pumped Storage Plant (conventional) of the Virginia Electric Power Co. was the largest conventional pumped storage plant in operation in 1976. It had a 2000 MW capacity and a 331 m (1090 ft.) head and cost $399/kW (1977 prices). Typical conventional hydroelectric pumped storage cost data are shown on Table IX-1.

9.4 Variable Production Costs

The variable production dosts of the thermal units operating in systems with UHPS and its alternatives are derived

TABLE IX-1

PUMPED STORAGE COST DATA *

	Year of Initial Operation	Capacity in MW	Hours	Facility Storage/Cost $/kWh (1974)	(1977)	Power Cost $/kW (1974)	(1977)	Total Costs $/kW (1974)	(1977)
Taum Sauk	1963	350	7.7	9.87	13.22	158	212	234	314
Yards Creek	1965	330	8.75	3.54	4.74	136	182	167	224
Muddy Run	1967	855	14.25	11.89	15.93	129	173	156	209
Cabin Creek	1967	280	5.85	11.45	15.34	124	166	191	256
Seneca	1969	380	11.2	6.34	8.50	186**	249	257	344
Northfield Mtn.	1972	1000	8.5	1.71	2.29	132	177	146.5	196
Blenheim-Gilboa	1973	1030	11.6	3.45	4.62	100	134	140	188
Ludington	1973	1675	9	8.44	11.31	125	168	201	269
Jocassee	1973	625	94	.69	.92	117.5	157	182.5	245
Bear Swamp	1974	540	5.6	12.86	17.23	141	189	213	285
Raccoon Mountain	1975	1370	24	1.25	1.68	87	117	117	157
UHPS	1977	2000	6.0		14.10		177		267
		2000	8.0		14.10		177		290
		2000	10.0		14.10		177		318

* 1974 Dollars 1977 factor - 1.34 (Handy-Whitman)

** Adjusted to $175/KW to eliminate costs associated with downstream discharge which permits the plant to utilize the head created by the lower reservoir dam for generation.

Source: Table II-1, Study 2, Public Service E&G of New Jersey by simulating the hour-by-hour operation of typical electric systems with characteristic loads and a generation mix having heat rates, fuel, operation and maintenance costs, and forced and maintenance outage rates as reported in Ref. 9, Table II-2 and tabulated in Tables IX-2 and VIII-5.

According to Consulting Engineering Magazine (April 1978), a recent EPRI study shows that coal-fired plants can be economically attractive in all regions of the United States. Based on 1976 dollars, the capital cost ranged from $520 to $810 per kW, with a median range of $610 to $724 per kW. (These costs included interest during construction, gas cleaning, and contingencies. UHPS pricing of this study does not include AFDC, but does include contingencies.) The high price coal plants included allowance for unusual environmental conditions and seismic activity.

UHPS has an advantage over conventional pumped storage in that its lower reservoir is unexposed to wind and sun and thus is not as subject to evaporation losses and reduced makeup water need. On the other hand, the longer construction period for UHPS, compared to other alternatives, does result in increased costs for interest during construction. This is an economic disadvantage which cannot be ignored.

A further inspection of the EPRI study reveals that the national average of coal costs (excluding the south central region) in 1976 was $0.92/MB and is forecast at $1.14/MB by the year 2000. Using a CFCP with a heat rate of 10,000 B/kWh, this yields a fuel generation cost of 9.2 mils/kWh and 11.4 mils/kWh, respectively. The south central region was excluded from the average as its figure was one-half of the average without its inclusion.

TABLE IX-2

THERMAL UNIT HEAT RATES

Typical Fossil Generation Unit Net Heat Rates

Fossil Unit Description	Unit Rating (MW)	100% Output (Btu/kWh)	80% Output (Btu/kWh)	60% Output (Btu/kWh	40% Output (Btu/kWh)	25% Output (Btu/kWh)
Steam - Coal	50	11000	11088	11429	12166	13409*
Steam - Oil	50	11500	11592	11949	12719	14019*
Steam - Gas	50	11700	11794	12156	12940	14262*
Steam - Coal	200	9500	9576	9871	10507	11581*
Steam - Oil	200	9900	9979	10286	10949	12068*
Steam - Gas	200	10050	10130	10442	11115	12251*
Steam - Coal	400	9000	9045	9252	9783	10674*
Steam - Oil	400	9400	9447	9663	10218	11148*
Steam - Gas	400	9500	9548	9766	10327	11267*
Steam - Coal	600	8900	8989	9265	9843	10814*
Steam - Oil	600	9300	9393	9681	10286	11300*
Steam - Gas	600	9400	9494	9785	10396	11421*
Steam - Coal	800-1200	8750	8803	9048	9625*	
Steam - Oil	800-1200	9100	9155	9409	10010*	
Steam - Gas	800-1200	9200	9255	9513	10120*	
Steam - Coal**	900	10470	10600	11300	12750	15752
Comb. Turb. **	50	14000	14300	15600	19200	23800

* For study purposes, units should not be loaded below the points shown.

** Cycling units and C. T. heat rates assumed by MAIN.

TABLE IX-2 (Continued

Typical Nuclear Generation Net Heat Rates

Unit Description	100% Output (Btu/kWh)	75% Output (Btu/kWh)	50% Output (Btu/kWh)
Light Water Reactor	10400	10442*	10951*

* Nuclear units are usually dispatched at fixed output.

Typical Combustion Turbine Generation Unit
Net Heat Rate

Unit Type	Heat Rate (Btu/kWh)
Industrial	14000

9

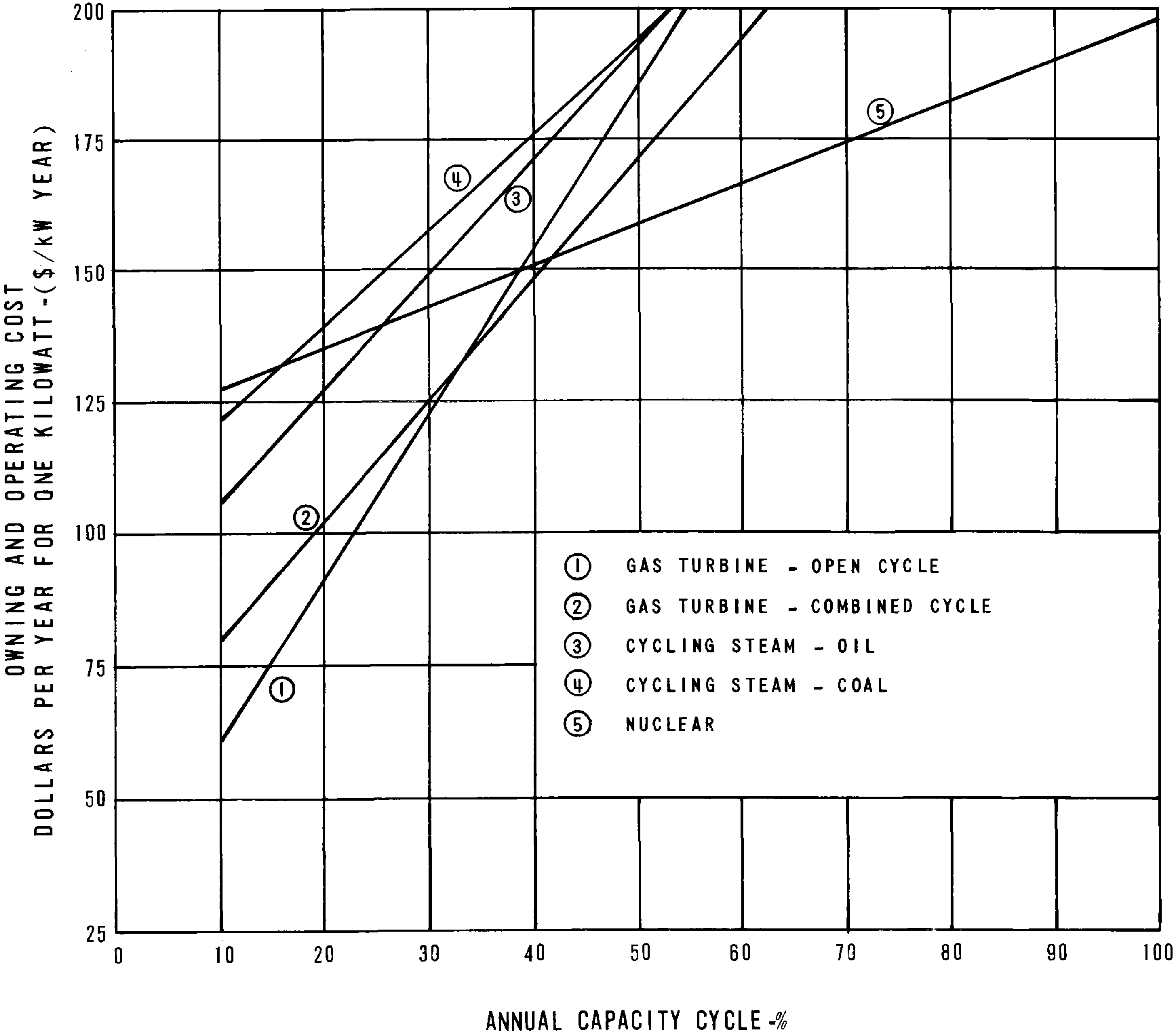
The cost of oil, as a fuel source, will far exceed that of coal as evidenced by the fact that in 1974 the U. S., as a whole, utilized as an electric generation fuel source 45% coal versus 16% petroleum products.

9.5 Comparative Fixed and Variable Costs of UHPS and Alternatives

An analysis of the owning and operating costs of UHPS and thermal plants shows that UHPS has the cheapest fixed operation and maintenance costs: UHPS - $1.75/yr/kWh; combustion turbines - $2.00; coal-fire cycling plants - $4.00 (Tables IX-3 and IX-4). The owning and operating costs for Scenario D for UHPS, with 6 hour storage for UHPS (10% capacity factor), is $38.8 per year for one (1) kWh, as compared with the range for alternatives as shown on Table IX-5 for 20% capacity factor. The owning and operating costs at varying capacities are shown on Plate IX-1.

9.6 Supplemental Data

Nuclear power data, although least costly (mils per kWh), are not, however, comparative inasmuch as its role is base power whereas UHPS is peaking power operating at a significantly lower capacity factor. A second consideration is the expected plant life. UHPS is computed at a plant life of 50 years, with an actual potential life exceeding this possibly to 100 years. The lives of alternative generating systems are in the range of 35 to 40 years. Thirdly, the fuel source (other than pumping energy) of UHPS is inexhaustible and reusable, which is not true in the life span of the alternatives. Added to this is the impact of escalation in



MAIN

PLATE IX-1

price on other fuels attendant to diminishing supplies. Historically, pumped storage has lower outage rates (and/or maintenance) than other alternatives, possibly excluding straight hydro.

TABLE IX-3

FIXED AND VARIABLE COSTS
(Owning and Operating Costs vs. Duty Cycle)

	Scenario A	Scenario D		
		6 Hr	8 Hr	10 Hr
Annual Capacity Factor(1)	10%	10%	10%	10%
Fixed Charges(2)	29.7	28.2	30.7	33.2
Fixed O. & M.	2.3	2.3	2.3	2.3
Fuel(3)	13.0	13.8	13.8	13.8
Total - mils/KWH	45.0	44.3	46.8	49.3

(1) Annual capacities encountered in system simulation ranged from 10-15% when pumped storage is utilized to maximum economic advantage.

(2) Based on a 10% weighted cost of capital and 8% escalation.

(3) Equivalent fuel costs for pumped storage obtained by dividing the average cost of pumping energy by the cycle efficiency of 70%.

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TABLE IX-4

ESTIMATED ANNUAL OUTAGE RATES

THERMAL AND HYDRO UNITS

THERMAL UNITS	INSTALLED CAPACITY (MW)	SCHEDULED MAINTENANCE (WEEKS)	FORCED OUTAGE AND UNSCHEDULED MAINTENANCE (% OF YEAR)
Coal Fired Steam	50.	2	4.9
Coal Fired Steam	200.	3	10.3
Coal Fired Steam	400.	4	15.5
Coal Fired Steam	600.	4	22.4
Coal Fired Steam	1,000.	5	23.8
Coal Fired Steam	1,200.	5	23.8
Coal Fired Cycling	500.	4	22.4
Coal Fired Cycling	600.	4	22.4
Oil Fired Steam	200.	3	10.3
Oil Fired Steam	400.	4	15.5
Oil Fired Steam	800.	5	23.8
Combustion Turbine	50.	1	25.7
Nuclear	1,000.	5	16.0
Nuclear	1,200.	5	16.0
Hydro			
Conventional	-	2	1.2
Pumped Storage	-	5	5.0 *

* Based on limited data.

TABLE IX

REPRESENTATIVE ELECTRIC GENERATING COSTS

	(OPEN CYCLE)	GAS TURBINE COMBINED CYCLE (Note 2)	CYCLING STEAM		NUCLEAR
Fuel	Oil	Oil	Coal	Oil	Nuclear
Size Range - MW	10-100	100-400	400-600	400-600	600-1300
Capital Investment - $/kW	180	350	650	520	750
Start-up Time	5-10 Min.	a) G.T. = 5-10 Min. b) BLR & T-G - 6 Hrs.	6-8 Hrs.	6-8 Hrs.	12 Hrs
Lead Time (Overnight Shutdown)	5-10 Min.	a) G.T. = 5-10 Min. b) BLR & T-G = 90 Min.	2 Hrs.	2 Hrs.	12 Hrs
Heat Rate - Btu/kWh (Higher Heating Values)	12,000	8,500	10,000	9,800	10,900
Fuel Cost - $/Million Btu	2.60	2.60	1.25	2.20	0.60
Fuel Capability	a) Gas b) #2 Distillate Oil	a) G.T. - Gas or #2 Distillate Oil b) BLR & T-G = Unfired	a) #6 Oil b) Coal	#6 Oil	Nuclear

Owning & Operating Costs vs. Duty Cycle - $ Per Year for One kWh

	10%	20%	20%	40%	20%	40%	20%	40%	50%	100%
Fixed Charges	28.8	28.8	56.0	56.0	104.0	104.0	83.0	83.0	120.0	120.0
O&M - Fixed	2.0	2.0	2.5	2.5	4.0	4.0	2.5	2.5	2.0	2.0
Variable	2.3	6.0	4.7	11.9	10.0	24.0	3.7	9.9	8.0	18.0
Fuel	27.3	54.6	38.7	77.4	21.9	43.8	37.7	75.4	28.6	57.2
TOTAL	59.4	91.4	101.9	147.8	139.9	175.8	126.9	170.8	158.6	197.2

Owning & Operating Costs vs. Duty Cycle - Mills/kWh

	10%	20%	20%	40%	20%	40%	20%	40%	50%	100%
Fixed Charges	20.5	10.3	20.0	10.0	37.1	18.0	29.7	14.8	17.1	8.6
O&M	4.9	4.6	4.1	4.1	8.0	8.0	3.5	3.5	2.3	2.3
Fuel	31.2	31.2	22.1	22.1	12.5	12.5	21.6	21.6	6.5	6.5
TOTAL	56.6	46.1	46.2	36.2	57.6	39.1	54.8	39.9	25.9	17.4

Notes:

1. Values are based on 1977 costs within continental limits of the Unted States.
2. Combined cycles are assumed to generate 2/3 of total power output on gas turbines and 1/3 of total power on steam turbine-generator at 100% rating. At partial loads, it is assumed that each of the on-line gas turbines generates 100% of its unit capability.
3. For purposes of simplification, it is assumed that whenever a unit is on-line, it is operated at 100% rating.

REVISED - AUGUST 24, 1977

10.0 RECOMMENDED RESEARCH PROGRAM

Operationally, there are no basic differences in the principles of conventional pumped storage and UHPS. The difference in the two systems is threefold: head - with conventional pumped storage normally under 300 m (1000 ft.), whereas recommended depths for UHPS are 1000 to 1500 m (3300 to 4900 ft.); the marked larger rock excavation for the underground reservoir and powerhouse; and the turbine/pump units to accommodate the head difference.

10.1 Field Investigations

Reliable information anent the rock conditions for UHPS must be known from the upper surface to the lower reservoir. This data can and well may differ between potential sites. Considering that only approximately 20% of geological sites may be capable of development, it is questionable that an exploratory program, per se, be undertaken. Such investigations, important as they are, should be site specific.

One facet which is difficult to assess, based on presently available techniques, is the in-situ stress level at the lower reservoir depth. Stress levels for rock at great depth is an important design and cost concern in cavern support. To date, such determinations have been limited to comparatively shallow depths of only several hundred meters. Investigations of conditions at the greater depths of UHPS would provide a valuable contribution to rock science, if undertaken under a controlled program.

Hydrofracturing should be considered as a practical method in determining in situ stresses. Although it was successfully used at the Helms Pumped Storage Project, California, it is still in its experimental stages. Its use at substantial depths, e.g. 1200 m (4,000 ft.) and greater should be considered as a fitting research project for UHPS.

10.2 Design and Construction

Design and construction research potentials are minimal. Design opportunities are basically limited to: configuration and air evacuation of the lower reservoir; heat transfer from deep rock; mineralization of stored water; and eutrophication impacts. The construction of shafts and underground caverns introduce no new problems. Heading and benching methods are conventional and are well known worldwide. Consideration might be given to "tracking" of "evolutionary" methods of underground excavation methods as a palliative to cost and the preparation of a compendium of methods, if deemed meritorious. This could be equally true of a standard rock excavation manual from which pertinent extracts could be inserted into bid documents by reference. This could minimize the number of disputes and contractors' claims during construction.

10.3 Equipment

With the exception of the multi-stage reversible single drop unit, equipment falls within the state-of-the-art and manufacturing capability. Yet the multi-stage unit holds the greatest promise for the requisite head, both operationally and cost-wise. The "cascading" type arrangement involves an intermediate reservoir and powerhouse with possible operation problems, and the tandem scheme requires double equipment.

The multi-stage reversible units are in the early stage of development. Experience, to date, is limited although several European firms have done research and at least one such pump/turbine for La Coche has been designed and manufactured (930 m or 3000 ft. head). Assurances have been given that equipment could be manufactured to meet specifications recommended herein. Although certain modifications, with probable research, would be necessary, it is certain this could be done - if there were to be an actual project need. Further attention is called to the ANL program in Paragraph 3.6.6.

10.4 Others

Two other potential research efforts could be: optimum maximum head, assuming uniform competent geologic conditions, and applying the present worth method, or any other equivalent method with sensitivity analysis for pertinent factors, to the overall project economic evaluation. Secondly, system simulations extended to cover additional systems, future years, and more than one increment of UHPS.

Although the above research suggests those of major import it is conceded that in any developing concept there may surface many other items deserving attention, some site specific and others broad in nature.

11.0 Program of Development

Due to the recent concept of UHPS, knowledge of details has been limited, acceptance minimal, and implementation nil. Yet, the generation pattern does not differ from that of conventional pumped storage. Price is competitive and, under acceptable geologic conditions, UHPS has the potential of location nearer to demand center with resulting attendant economies and conveniences. Yet, to date, UHPS has had little attractiveness to the Electric Utilities Industry. This could possible be induced by (1) the large volume of rock excavation and finite costs and disposal thereof, and (2) the impact of interest during construction due to the comparatively longer construction period.

Its potentials being essentially unknown, it becomes apparent that if UHPS is to become a viable component of the generation mix, a sponsorship is required to tutorially make known its details, advantages, and disadvantages to decision-makers. Its disadvantages, other than restricted implementation because of rock competency, such as heat transfer, water quality, and eutrophication, have been cited. Its countering advantages are countable, including dependability of water supply free of seasonal influences, reduced environmental restraints due to elimination of exterior lower reservoir, especially costly fish ladders, and safety against harmful impacts of natural and aggressive actions.

Sponsorship, for example, might well be undertaken by a Federal Agency, such as the Department of Energy. This could take the form of a continuing educational program. It could include seminars for areal sectors of the Electric Industry,

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papers at annual meetings of engineering societies, such as the American Society of Civil Engineers and the Power Engineering Society of IEEE, and selected articles for release to engineering media. In this manner, UHPS can escape from the position of an untried engineering theory to that of a real consideration in the expansion of electric generation.

APPENDICES

A

APPENDIX I

COST ESTIMATE SUMMARY

SCHEME I TO VII

COST ESTIMATE SUMMARY

SCHEME I:	Capacity:	2000 MW (6 units)
	Av. Gross Head:	1200 m (one drop)
	Storage:	10 hours
	Units:	Multi Stage Reversible

ITEM NO.	DESCRIPTION	AMOUNT($x10^3)
333	LAND & LAND RIGHTS	2,000
331	POWER PLANT STRUCTURES & IMPROVEMENTS	
	Main Equipment Shaft	17,835
	Cable Shaft	14,330
	Underground Power House	25,026
	Gate Gallery	1,145
	Above Ground Structures	1,500
	SUBTOTAL	61,836
332	RESERVOIRS, DAMS & WATERWAYS	
	Upper Reservoir, Dam & Reservoir	19,131
	Upper Reservoir, Intake	1,700
	Lower Reservoir:	
	Excavation	138,750
	Rockbolting & Shotcrete	28,591
	Disposal	16,068
	Water Conductors:	
	Penstock Shaft	15,251
	Manifold	14,809
	Draft Tunnels	4,244
	Lower Reservoir, Ventilation Shaft	10,512
	Construction Adits	3,920
	Reservoir Filling	2,000
	SUBTOTAL	254,975
333	PUMP/TURBINES & GENERATOR/MOTORS	
	Pump/Turbines, Governors, Valves & Installation	66,000
	Generator/Motors, Starting Equipment & Installation	45,000
	SUBTOTAL	111,000
334	ACCESSORY ELECTRICAL EQUIPMENT	
	High Voltage Buses	9,060
	All Other Electrical Equipment	19,547
	SUBTOTAL	28,607
335	MISCELLANEOUS MECHANICAL EQUIPMENT	
	Cranes & Hoists	9,610
	All Other Mechanical Equipment	6,000
	SUBTOTAL	15,610

ITEM NO.	DESCRIPTION		AMOUNT ($x10^3)
336	ROADS & BRIDGES		5,000
	SUBTOTAL DIRECT COSTS		477,029
	CONTINGENCIES:	Equipment 10%	15,522
		Underground Civil 25%	68,603
		Above Ground Civil 15%	7,110
	SUBTOTAL		568,264
	ENGINEERING, SUPERVISION & OVERHEAD		68,192
	TOTAL		636,455
	$/kW		318

NOTE:
Based on Unit Prices of January 1977

COST ESTIMATE SUMMARY

SCHEME II: Capacity: 2000 MW (2x4 units)
Av. Gross Head: 2x600 m (two drops)
Storage: 10 hours
Units: Single Stage, Reversible

ITEM NO.	DESCRIPTION	AMOUNT ($x10^3)
333	LAND & LAND RIGHTS	2,000
331	POWERPLANT STRUCTURES & IMPROVEMENTS	
	Main Equipment Shaft	17,212
	Cable Shaft	14,023
	Underground Power House	40,228
	Gate Gallery	1,646
	Above Ground Structures	1,500
	SUBTOTAL	76,609
332	RESERVOIRS, DAMS & WATERWAYS	
	Upper Reservoir, Dam & Reservoir	19,131
	Upper Reservoir Intake	1,700
	Intermediate Reservoir:	
	Excavation	9,094
	Intake	1,000
	Lower Reservoir:	
	Excavation	138,750
	Rockbolting & Shotcrete	28,591
	Disposal	16,068
	Water Conductors:	
	Penstock Shaft	14,594
	Manifold	17,432
	Draft Tunnels	6,350
	Lower Reservoir Ventilation Shaft & Spillway Shaft	17,265
	Construction Adits	5,770
	Reservoir Filling	2,000
	SUBTOTAL	277,745
333	PUMP/TURBINES & GENERATOR/MOTORS	
	Pump/Turbines, Governors, Valves & Installation	37,600
	Generator/Motors, Starting Equipment & Installation	42,900
	SUBTOTAL	80,500
334	ACCESSORY ELECTRICAL EQUIPMENT	
	High Voltage Buses	9,740
	All Other Electrical Equipment	21,955
	SUBTOTAL	31,695
335	MISCELLANEOUS MECHANICAL EQUIPMENT	
	Cranes & Hoists	10,120
	All Other Mechanical Equipment	8,000
	SUBTOTAL	18,120

ITEM NO.	DESCRIPTION		AMOUNT ($x10³)
336	ROADS & BRIDGES		5,000
	SUBTOTAL DIRECT COSTS		489,669
	CONTINGENCIES:	Equipment 10%	13,032
		Underground Civil 25%	77,989
		Above Ground Civil 15%	7,110
	SUBTOTAL		587,800
	ENGINEERING, SUPERVISION & OVERHEAD		70,536
	TOTAL		658,336
	$/kW		329

NOTE:
Based on Unit Prices of January 1977

COST ESTIMATE SUMMARY

SCHEME III: Capacity: 2000 MW (6 units)
Av. Gross Head 1200 m (one drop)
Storage: 10 hours
Units: Tandem

ITEM NO.	DESCRIPTION	AMOUNT ($x10^3)
333	LAND & LAND RIGHTS	2,000
331	POWERPLANT STRUCTURES & IMPROVEMENTS	
	Main Equipment Shaft	16,976
	Cable Shaft	13,220
	Underground Powerhouse	29,715
	Gate Gallery	1,413
	Above Ground Structures	1,500
	SUBTOTAL	64,824
332	RESERVOIRS, DAMS & WATERWAYS	
	Upper Reservoir, Dam & Reservoir	19,131
	Upper Reservoir Intake	1,700
	Lower Reservoir:	
	Excavation	138,750
	Rockbolting & Shotcrete	28,591
	Disposal	16,068
	Water Conductors:	
	Penstock Shaft	14,473
	Manifold	21,546
	Donwstream Tunnels & Shafts	2,212
	Lower Reservoir, Ventilation Shaft	9,737
	Construction Adits	3,920
	Reservoir Filling	2,000
	SUBTOTAL	258,128
333	PUMP/TURBINES & GENERATOR/MOTORS	
	Pump/Turbines, Governors, Valves & Installation	102,000
	Generator/Motors, Starting Equipment & Installation	47,000
	SUBTOTAL	149,000
334	ACCESSORY ELECTRICAL EQUIPMENT	
	High Voltage Buses	9,060
	All Other Electrical Equipment	19,547
	SUBTOTAL	28,607
335	MISCELLANEOUS MECHANICAL EQUIPMENT	
	Cranes & Hoists	9,610
	All Other Mechanical Equipment	7,000
	SUBTOTAL	16,610

ITEM NO.	DESCRIPTION		AMOUNT ($x10^3)
336	ROADS & BRIDGES		5,000
	SUBTOTAL DIRECT COSTS		552,169
	CONTINGENCIES:	Equipment 10%	19,422
		Underground Civil 25%	70,138
		Above Ground Civil 15%	7,110
	SUBTOTAL		618,839
	ENGINEERING, SUPERVISION & OVERHEAD		74,261
	TOTAL		693,100
	$/kW		346

NOTE:
Based on Unit Prices of January 1977

COST ESTIMATE SUMMARY

SCHEME IV: Capacity: 2000 MW (6 units)
Av. Gross Head: 1500 m (one drop)
Storage: 10 hours
Units: Multi Stage Reversible

ITEM NO.	DESCRIPTION	AMOUNT ($x10^3$)
333	LAND & LAND RIGHTS	1,900
331	POWERPLANT STRUCTURES & IMPROVEMENTS	
	Main Equipment Shaft	21,015
	Cable Shaft	16,189
	Underground Powerhouse	25,664
	Gate Gallery	1,145
	Above Ground Structures	1,500
	SUBTOTAL	67,413
332	RESERVOIRS, DAMS & WATERWAYS	
	Upper Reservoir, Dam & Reservoir	16,498
	Upper Reservoir Intake	1,300
	Lower Reservoir:	
	Excavation	110,671
	Rockbolting & Shotcrete	28,506
	Disposal	12,800
	Water Conductors:	
	Penstock Shaft	15,939
	Manifold	14,312
	Draft Tunnels	4,220
	Lower Reservoir Ventilation Shaft	12,500
	Construction Adits	3,920
	Reservoir Filling	1,900
	SUBTOTAL	222,566
333	PUMP/TURBINES & GENERATOR/MOTORS	
	Pump/Turbines, Governors, Valves & Installation	82,000
	Generator/Motors, Starting Equipment & Installation	45,000
	SUBTOTAL	127,000
334	ACCESSORY ELECTRICAL EQUIPMENT	
	High Voltage Buses	11,500
	All Other Electrical Equipment	19,547
	SUBTOTAL	31,047
335	MISCELLANEOUS MECHANICAL EQUIPMENT	
	Cranes & Hoists	9,800
	All Other Mechanical Equipment	6,000
	SUBTOTAL	15,800

ITEM NO.	DESCRIPTION		AMOUNT ($\$ \times 10^3$)
336	ROADS & BRIDGES		5,000
	SUBTOTAL DIRECT COSTS		468,826
	CONTINGENCIES:	Equipment 10%	17,385
		Underground Civil 25%	63,520
		Above Ground Civil 15%	6,135
	SUBTOTAL		555,866
	ENGINEERING, SUPERVISION & OVERHEAD		66,704
	TOTAL		622,570
	$/kW		311

NOTE:
Based on Unit Prices of January 1977

COST ESTIMATE SUMMARY

SCHEME V: Capacity: 2000 MW (6 units)
Av. Gross Head: 900 m (one drop)
Storage: 10 hours
Units: Multi Stage Reversible

ITEM NO.	DESCRIPTION	AMOUNT($x10^3)
333	LAND & LAND RIGHTS	2,200
331	POWERPLANT STRUCTURES & IMPROVEMENTS	
	Main Equipment Shaft	14,668
	Cable Shaft	11,657
	Underground Powerhouse	28,400
	Gate Gallery	1,145
	Above Ground Structures	1,500
	SUBTOTAL	59,570
332	RESERVOIRS, DAMS & WATERWAYS	
	Upper Reservoir, Dam & Reservoir	23,820
	Upper Reservoir Intake	2,000
	Lower Reservoir:	
	Excavation	184,851
	Rockbolting & Shotcrete	28,568
	Disposal	21,500
	Water Conductors:	
	Penstock Shaft	14,059
	Manifold	14,648
	Draft Tunnels	4,620
	Lower Reservoir Ventilation Shaft	8,373
	Construction Adits	3,920
	Reservoir Filling	2,200
	SUBTOTAL	308,559
333	PUMP/TURBINES & GENERATORS/MOTORS	
	Pump/Turbines, Governors, Valves & Installation	66,000
	Generator/Motors, Starting Equipment & Installation	44,000
	SUBTOTAL	110,000
334	ACCESSORY ELECTRICAL EQUIPMENT	
	High Voltage Buses	7,650
	All Other Electrical Equipment	19,547
	SUBTOTAL	27,197
335	MISCELLANEOUS MECHANICAL EQUIPMENT	
	Cranes & Hoists	9,400
	All Other Mechanical Equipment	6,000
	SUBTOTAL	15,400

ITEM NO.	DESCRIPTION		AMOUNT ($x10^3)
336	ROADS & BRIDGES		5,000
	SUBTOTAL DIRECT COSTS		525,726
	CONTINGENCIES:	Equipment 10%	15,260
		Underground Civil 25%	78,727
		Above Ground Civil 15%	8,733
	SUBTOTAL		628,446
	ENGINEERING, SUPERVISION & OVERHEAD		75,413
	TOTAL		703,859
	$/kW		352

NOTE:
Based on Unit Prices of January 1977

COST ESTIMATE SUMMARY

SCHEME VI:
- Capacity: 2700 MW (8 units)
- Av. Gross Head: 1200 m (one drop)
- Storage: 10 hours
- Units: Multi Stage Reversible

ITEM NO.	DESCRIPTION	AMOUNT ($x10^3)
333	LAND & LAND RIGHTS	2,200
331	POWER PLANT STRUCTURES & IMPROVEMENTS	
	Main Equipment Shaft	17,835
	Cable Shaft	14,056
	Underground Powerhouse	31,851
	Gate Gallery	1,525
	Above Ground Structures	1,500
	SUBTOTAL	68,967
332	RESERVOIRS, DAMS & WATERWAYS	
	Upper Reservoir, Dam & Reservoir	23,638
	Upper Reservoir Intake	2,000
	Lower Reservoir:	
	Excavation	186,945
	Rockbolting & Shotcrete	38,625
	Disposal	21,600
	Water Conductors:	
	Penstock Shaft	16,253
	Manifold	21,770
	Draft Tunnels	5,650
	Lower Reservoir Ventilation Shaft	11,050
	Construction Adits	3,920
	Reservoir Filling	2,200
	SUBTOTAL	333,651
333	PUMP/TURBINES & GENERATOR/MOTORS	
	Pump/Turbines, Governors, Valves & Installation	89,200
	Generator/Motors, Starting Equipment & Installation	60,800
	SUBTOTAL	150,000
334	ACCESSORY ELECTRICAL EQUIPMENT	
	High Voltage Buses	12,250
	All Other Electrical Equipment	23,800
	SUBTOTAL	36.050
335	MISCELLANEOUS MECHANICAL EQUIPMENT	
	Cranes & Hoists	9,610
	All Other Mechanical Equipment	8,100
	SUBTOTAL	17,710

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ITEM NO.	DESCRIPTION		AMOUNT ($x10^3)
336	ROADS & BRIDGES		5,000
	SUBTOTAL DIRECT COSTS		611,378
	CONTINGENCIES:	Equipment 10%	20,376
		Underground Civil 25%	86,595
		Above Ground Civil 15%	9,186
	SUBTOTAL		727,535
	ENGINEERING, SUPERVISION & OVERHEAD		87,304
	TOTAL		814,839
	$/kW		302

NOTE:
Based on Unit Prices of January 1977

COST ESTIMATE SUMMARY

SCHEME VII: Capacity: 1300 MW (4 units)
Av. Gross Head: 1200 m (one drop)
Storage: 10 hours
Units: Multi Stage Reversible

ITEM NO.	DESCRIPTION	AMOUNT ($x10^3)
333	LAND & LAND RIGHTS	1,900
331	POWER PALNT STRUCTURES & IMPROVEMENTS	
	Main Equipment Shaft	17,835
	Cable Shaft	14,056
	Underground Powerhouse	18,205
	Gate Gallery	765
	Above Ground Structures	1,500
	SUBTOTAL	54,261
332	RESERVOIRS, DAMS & WATERWAYS	
	Upper Reservoir, Dam & Reservoir	13,673
	Upper Reservoir Intake	1,300
	Lower Reservoir:	
	Excavation	89,734
	Rockbolting & Shotcrete	18,540
	Disposal	10,350
	Water Conductors:	
	Penstock Shaft	12,851
	Manifold	9,575
	Draft Tunnels	2,820
	Lower Reservoir Ventilation Shaft	10,450
	Construction Adits	3,920
	Reservoir Filling	1,900
	SUBTOTAL	175,113
333	PUMP/TURBINES & GENERATOR/MOTORS	
	Pump/Turbines, Governors, Valves & Installation	43,000
	Generator/Motors, Starting Equipment & Installation	29,300
	SUBTOTAL	72,300
334	ACCESSORY ELECTRICAL EQUIPMENT	
	High Voltage Buses	5,880
	All Other Electrical Equipment	14,000
	SUBTOTAL	19,880
335	MISCELLANEOUS MECHANICAL EQUIPMENT	
	Cranes & Hoists	9,610
	All Other Mechanical Equipment	4,000
	SUBTOTAL	13,610

ITEM NO.	DESCRIPTION		AMOUNT ($x10^3)
336	ROADS & BRIDGES		5,000
	SUBTOTAL DIRECT COSTS		340,164
	CONTINGENCIES:	Equipment 10%	10,579
		Underground Civil 25%	49,688
		Above Ground Civil 15%	5,343
	SUBTOTAL		405,774
	ENGINEERING, SUPERVISION & OVERHEAD		48,693
	TOTAL		454,467
	$/kW		350

NOTE:
Based on Unit Prices of January 1977

APPENDIX II

COST DEVELOPMENT OF EXCAVATION FOR UNDERGROUND RESERVOIR IN SCHEME I

COST DEVELOPMENT OF EXCAVATION FOR UNDERGROUND RESERVOIR IN SCHEME 1

Basic Assumptions:

Cost level as of January 1977.

Chicago wage scales.

Construction Schedule: 3 shifts per day and 6 days per week. Two mucking shafts, plus one shaft for personnel and service. Each mucking shaft requires one double drum production hoist using two 24-ton skip hoists. The time for the skip hoist to travel 4000 feet, including acceleration and deceleration equals 1.48 minutes. The time to dump or fill equals 0.22 minutes - or a hoist cycle time of 2.0 minutes. Rock density is $2.8 \times \frac{1000.9\ kg}{M^3}$ - or rock density = 2.80t per M^3.

Excavation:

Volume of heading = 1,875,000 M^3 (2,450,625 c.y.)

Volume of benching = 5,547,000 M^3 (7,249,929 c.y.)

Efficiency and Productive Time Per Day for Hoists:

Non-productive

Coffee breaks	- 20 minutes
Portal to Portal	- 30 minutes
Wash-up	- 15 minutes
Lunch	- 30 minutes

95 min. x 3 shifts = 285 min. = 4.75 hrs.

$$\text{Efficiency} = \frac{24 - 4.75\ \text{hrs.}}{24\ \text{hrs.}} \times 80\% = 64\%$$

Heading Excavation:

Max. prod. rate for 1 hoist at 100% eff. = $\frac{60\ \text{Min}}{2.0\ \text{Min}} \times 24T \times \frac{2000}{2200}$ = 654/5 metric tons

654.5 Tons/hr x $\frac{1\ cy}{2.80}$ = 233.8Bm^3/hr at 100% eff. (305 c.y./hr)

1 hoist prod/day = 233.8 m^3/hr x 24 hr x 64% eff. = 3590Bm^3 (4692 c.y.) solid rock

Bm^3 = cu.m solid rock

Time required to excavate Lower Reservoir, using 2 shafts:

$$\frac{7,428,000\ m^3}{2 \times 3590\ m^3/\text{day}} = 1035\ \text{days}$$

Required heading crews to excavate 7180 BM^3 (2 shifts)

Face area $= \dfrac{\pi\ (15.0)^2}{4 \times 2} = 88.36\ m^2$ (950.6 sq. ft.)

Vol. per 3.96 m round = 88.36 x 3.96 = 349.9 BM^3 (457.3 c.y.)

Number of holes per round = 88.36 x 1.54 = 136

Number of drills $= 88.36\ m^2 \times \dfrac{1}{3.25} = 27$

Each rig has 8 drills $\therefore\ \dfrac{27}{8} = 3.4$ Use 4 rigs

$\therefore$ Required drill crews = 4

Total rounds in heading = 1,870,000 ÷ 349.9 = 5347

Required working days $= \dfrac{1,871,000}{7180} = 261$ days

Required rounds per day $= \dfrac{5347}{261} = 20.5$

Number of Load-Haul Dumps (LHD) units

Haul distance = 2/3 x 1080 m = 720 m (2362 ft.)

Cycle:	Load	1.0 min.	
	Travel	1.5 min.	
	Dump	1.0 min.	
	Return & maneuver	2.2 min.	
		5.7 min.	Use 6 min.
			$\therefore$ 10 trips/60 min. hour
			8 trips/50 min. hour

1 LHD carries 7.65 m^3 x 8 x 5.71 hrs/shift = 312.1 Lm^3 (407.9 c.y.)/shift

* Lm^3 = loose cubic meters

Required number of LHD/shift $= \dfrac{2 \times 149.6 \times 1.5 \times 8}{312.1} = 11.5$ Use 12

Heading: Labor Per Shift:

Classification	Base Rate Incl. Fringe	X 1.6359 Total Rate	Shift Total
4 Drill Foremen	10.76	17.60	$ 563.20
32 Drillers	9.88	16.16	4,136.96
10 Laborers	9.63	15.75	1,260.00
4 Truck Drivers	10.05	16.44	526.08
4 Powder Men	10.76	17.60	563.20
6 Helpers	9.63	15.75	756.00
12 LHD Operators	12.00	19.63	1,884.48
1 Grader Operator		19.63	157.04
1 Dozer Operator		19.63	157.04
2 Surveyors		17.60	281.60
4 Scalers		15.75	504.00
80			$10,789.60

$$\text{Labor cost/m}^3 = \frac{\$10,789.60}{2 \times 1.49.6 \times 8} = \$4.51 \text{ BM}^3 \ (\$3.45/\text{c.y.})$$

Labor Burden

Workmen's Compensation	-	18.15%
Social Security Tax	-	4.20%
Federal Unemployment	-	0.40%
State Unemployment	-	3.50%
Public Liability	-	0.15%
		26.40%

$$\frac{\text{Hours Paid}}{\text{Hours Worked}} = \frac{9.625}{7.75} = 24.19\%$$

Average Shift Differential	8.00%
Underground Differential	5.00%
	63.59%

Heading/Material Costs: ($2,394\ BM^3$/shift)

Drill Steel: No. of Holes per Round = 88.36 x 1.54 = 136 Holes

Meters of Drilling per Round = 136 x 4.27 = 580.5 m (1904 ft.)

Rounds/shift: $\frac{20.5}{3} = 7$

M of drilling/shift = 4.27 x 136 x 7 = 4065 m (13,333 ft.)

M of drilling/BM^3 of solid rock = $\frac{4065}{2 \times 149.6 \times 8} = 1.70\ m/BM^3$ (4.27 ft/cy)

Cost/set = $226

Life = 610 m (2000 ft)

Cost/m = $\frac{\$226}{610'} = \$0.36$ ($0.11/ft)

Cost/shift = 4065 x $0.36 = $1466

Cost/BM^3 = $\frac{1466}{2394} = \$0.61/BM^3$ ($0.46/c.y.)

Bits:

Cost/bit (1-3/4") = $58

Life = 36.6 m (120 ft)

Cost/m^3 = $\frac{\$58}{36.60} = 1.58$ ($1.21/c.y.)

Cost/shift = 4065 x $1.58 = $6,400

Cost/m^3 = $\frac{\$6400}{2394m^3} = \$2.67/BM^3$ ($2.04/c.y.)

Caps:

Cap cost/hole = \$1.00 ea.

No. holes/shift = 136 x 7 = 936

Cost/shift = 936 x \$1.00 = \$936.00

$$\text{Cost/m}^3 = \frac{\$936}{2394\ \text{BM}^3} = 0.39 \quad (0.30/\text{c.y.})$$

Explosives:

Cost/kg Torvex = \$1.10

Powder factor 1.24 kg/m^3

Cost/shift = 2394 x 1.24 x 1.10 = \$3,279

$$\text{Cost/BM}^3 = \frac{\$3279}{2394} = 1.37/\text{M}^3 \quad (\$1.05/\text{c.y.})$$

1977 EQUIPMENT COST PER SHIFT
FOR HEADING OF UNDERGROUND STORAGE

Equipment	Equipment Costs Per Unit Per Hour				All Units
	Ownership Cost/Hr	Repair Cost/Hr	Operating Cost/Hr	Total Per Hr	Total Per Shift
4 Trucks for Jumbo 769B	4.36	8.42	9.73	22.51	$ 720.32
4 Drill Jumbos) 8 Drills per rig)	13.36	10.72	36.24	60.32	1,930.32
4 Pickups	0.38	0.23	2.25	2.86	91.52
4 Trucks/Explosives (9T)	1.36	3.06	0.75	5.17	165.44
4 Scalers				9.25	296.00
12 Eimco 920-C Muckers	7.16	10.86	38.35	56.37	5,411.52
5 Spares - Muckers	7.16	-	-	7.16	286.40
1 Dozer Cat. D-6	1.92	4.59	6.08	12.59	100.72
1 Grader Cat. 120	1.64	5.50	7.97	15.11	120.88
					$9,123.12

$$\text{Equipment Cost} = \frac{\$9123.12}{2394} = \$3.82/m^3 \quad (\$2.92/c.y.)$$

Underground Storage Heading Cost Summary:

Labor				4.51 per M^3
Material				
Drill Steel	.46			
Bits	2.04			
Caps	.30			
Explosives	1.05			
		3.85 per C.Y.	=	5.03 per M^3
Equipment		2.92 per C.Y.	=	3.82
		$10.22 per C.Y.		13.36 per M^3

<u>Benching Excavation</u>: 5,557,000 m^3; (2394 BM^3/shift)

1.5 x 1.5 m drill pattern; hole depth = 8.14 m

Required area to excavate per shift $\frac{2394\ m^3\ \text{solid rock}}{\text{shift}} = A;\ A \times \frac{1}{8.4} = 294.1\ m^2$ (3164 sq. ft.)

<u>Shift</u>:

Required LF of drilling/shift $= \frac{294.1 \times 8.44}{1.5 \times 1.5} = 1103$ m (3618 ft)

Required holes/shift $= \frac{294.1}{1.5 \times 1.5} = 130$ holes

Productive time/shift $= \frac{19.25\ \text{hrs}}{3} = 6.4$ hrs. for 60 min-hr

Productive time = 5.3 hrs for 50 min-hr

Time per hole and number of holes per shift per drill:

Set-up and move	10.0 minutes
Bit change 1 per hole	5.0 minutes
Pull steel for big change	0.2 minutes
Drill 27.7 ft x 1 min/ft	27.7 minutes
Retract steel	0.2 minutes
	43.1 minutes per hole

Holes per shift per drill $= \frac{5.3 \times 60\ \text{min}}{43.1} = 7.4$ holes

Number of drills $= \frac{126}{7.4} = 17$ drills

Benching: Labor Per Shift:

Classification	Total Rate	Total Per Shift
2 Drill Foremen	17.60	$ 281.60
1 Excavation Foreman	17.60	140.80
17 Drillers	16.16	2,197.76
8 Laborers	15.75	1,008.00
4 Powdermen	17.60	563.20
4 Helpers	15.75	504.00
2 Scalers	15.75	252.00
12 LHD Operators	19.63	1,884.48
1 Dozer Operator	19.63	157.04
1 Grader Operator	19.63	157.04
2 Surveyors	17.60	281.60
54		$7,427.52

Labor cost/M^3 = $\frac{\$7427.52}{2394\ m}$ = $3.11/$m^3$ (2.30/c.y.)

Materials Cost Per m^3:

Drill Steel: 1067 x $\frac{\$0.69}{2394cy}$ x $0.31/$m^3$ ($0.24/c.y.)

Bits: $\frac{1067}{2394}$ x $1.58 x $0.71/$m^3$ ($0.54/c.y.)

Explosives: 0.475 kg x $1.10 = $0.52/kg (0.40/c.y.)

Caps: $\frac{126\ holes}{2394}$ x $\frac{1\ cap}{hole}$ x $\frac{\$1.00}{cap}$ = $\frac{\$0.05/m^3}{\$1.59/m}$ $\frac{(\$0.04/c.y.)}{\$1.22/c.y.}$

EQUIPMENT COST PER SHIFT

FOR BENCHING OF UNDERGROUND STORAGE

(1977 Unit Prices)

Equipment	Equipment Costs Per Unit Per Hour				All Units
	Ownership Cost/Hr	Repair Cost/Hr	Operating Cost/Hr	Total Per Hr	Total Per Shift
17 Air Tracks	1.67	1.34	4.53	7.54	$1,025.44
5 Air Tracks - Spares	1.67	-	-	1.67	66.80
12 Muckers - 10 C.Y.	7.16	10.86	38.35	56.37	5,411.52
4 Muckers - Spares	7.16	-	-	7.16	229.12
2 Scalers	-	-	-	9.25	148.00
2 Pickups	0.38	0.23	2.25	2.86	45.76
2 Trucks/Explosives (9T)	1.36	3.06	0.75	5.17	82.72
1 Dozer Cat. D-6	1.92	4.59	6.08	12.59	100.72
1 Grader Cat. 120	1.64	5.50	7.97	15.11	120.88
					$7,230.96

Equipment Cost Per $m^3 = \frac{7,230.96}{2394} = \$3.02/m^3$ (2.33/c.y.)

Underground Storage Benching Cost Summary:

Labor			$3.11
Material			
	Drill Steel	$0.31	
	Bits	0.71	
	Caps	0.05	
	Explosives	0.52	1.59
Equipment			3.02
			$7.72/m^3 ($5.91/c.y.)

Hoists: (Underground Storage Vertical Mucking)

Hoist daily operating time using 2 hoists: $\frac{7,428,000}{7180}$ = 1035 days

Hoist hourly operating time: 1035 days x 64% x 24 hrs = 15,892 hrs

2 hoists: 2 x 15,898 hrs = 31,795 hrs

Labor:

	Rate	Total $/Hr
3 Hoist Operators	19.63	$ 58.89
3 Oilers	19.40	58.20
2 Gate Tenders	15.75	31.50
9 Helpers	15.75	141.75
		$ 290.34

1035 days x 24 hrs/day = 24,840 hrs

24,840 hrs x 290.34 = $7,212,000

Power:

15,892 hrs x 9747 kW x $.06 kWh = 9,300,000

$16,512,000

Power for Heading: 7442 kW x 261 days x 24 hrs x .06 = $2,797,000

Power for Benching: 8161 kW x 774 days x 24 hrs x .06 = $9,096,000

$11,893,000

Labor:

	Rate	Total $/Hr
Foreman	20.00	$ 20.00
3 Electricians	19.63	58.89
3 Pipefitters	19.63	58.89
6 Helpers	15.75	94.50
2 Truck Drivers	16.44	32.88
		$ 265.16

1035 days x $265.16/hr x 8 hrs/day = $2,196,000

Summary - Vent, Air, Water and Power:

Labor	$ 2,196,000	x	1.3*	=	$ 2,855,000
Power	$11,893,000	x	1.3	=	$15,461,000
Equipment	$ 538,000	x	1.3	=	$ 699,000
Materials	$ 4,005,000	x	1.3	=	$ 5,206,000
					$24,221,000

Bolts	$\frac{\pi\ (7.5)\ 21.170 \times 3.96}{1.728^2} \times 31.16$	= $20,612,000
Mesh	π (7.5) 21,170 x $2.406 x 30%	= $ 360,000
Shotcrete	π (7.5) 21.170 x 0.1524 x 261.4 x 33.6%	= $ 6,676,000
		$27,648,000

With Overtime:

27,648,000 x 1.03 = $28,591,000

* Overhead and Profit = 30% $\pm$ of direct cost

Summary - Underground Storage Excavation:

		($1,000)
Heading	1,875,000 M^3 x 13.36/M^3 x 1.3	32,589
Benching	5,547,000 M^3 x 7.74/M^3 x 1.3	55,915
Air, Water and Power		24,221
Hoists Operation		16,512
Crushing	(2,500,000 M^3 x $2.65)	6,625
		$135,862
Allowance for 6 days week .03 x 135,777 (Differential for Overtime impact on Labor)		4,073
Supports		28,591
Disposal	6,072,000 M^3 x 2.65	16,091
	GRAND TOTAL	$184,617

Cost per m^3 $= \frac{\$184,617,000}{7,432,000\ M^3} = \$24.84$ ($19.00/c.y.)

A

APPENDIX III

SCHEDULES OF CONSTRUCTION—UHPS

BUREAU OF RECLAMATION

DEPARTMENT OF ENERGY

UNDERGROUND PUMPED STORAGE
CONSTRUCTION SCHEDULE
(WITH ANNUAL DISBURSEMENTS)

SCHEME I: Capacity: 2000 MW (6 units)
Head: 1200 m, one drop
Storage: 10 hours
Units: Multi Stage Reversible

ITEM	Total Cost $1000 (Year →)	1	2	3	4	5	6	7	8
Mobilization	31,981	31,981							
Access Shafts and Penstock Shaft	35,416	3,935	15,740	15,741					
Lower Reservoir Ventilation Shaft	10,512				2,628	5,256	2,628		
Construction Adits and Loading Areas	3,920			3,920					
Intermediate Reservoir	———								
Lower Reservoir	163,428				46,694	46,694	46,694	23,346	
Powerhouse Excavation	10,010			1,581	8,429				
Powerhouse Concrete & Other Concrete	35,214				3,018	16,098	16,098		
Main Equipment Installation	120,610	CONTRACT AWARD				13,706	43,858	43,858	19,188
Auxiliary Equipment Installation	34,607					3,219	12,877	12,877	5,634
Testing and Commercial Operation								T_1 T_2 C_1	T_3 T_4 T_5 T_6 C_2 C_3 C_4 C_5 C_6
Upper Reservoir Bridges, and Roads	27,331				10,933	10,933	5,466		
SUBTOTAL DIRECT COST	473,029	35,926	15,740	21,242	71,702	95,905	127,621	80,081	24,822
Contingencies Civil Underground 25%	68,603		3,430	3,430	6,860	10,291	10,291	13,720	20,581
Contingencies Civil Above Ground 15%	7,110					1,422	3,555	2,133	
Contingencies Equipment 10%	15,522					1,552	4,657	4,657	4,656
SUBTOTAL CONTINGENCIES	91,235		3,430	3,430	6,860	13,265	18,503	20,510	25,237
SUBTOTAL	564,264	35,926	19,170	24,672	78,562	109,170	145,124	100,591	50,059
ENGINEERING SUPERVISION & OVERHEAD 12%	47,734	3,819	3,819	4,773	7,637	7,638	7,637	7,638	4,773
TOTAL	611,998	39,735	22,989	29,445	86,199	116,808	153,761	108,229	54,832

NOTES

Land was assumed bought before the Award of Civil Contract.
30% of Engineering and Overhead was assumed spent before construction started.
$24,457,000 considered spent before construction started.
T_n - start test on unit "n"
C_n - commercial operation of unit "n".

MAIN

BUREAU OF RECLAMATION

DEPARTMENT OF ENERGY

SCHEME II: Capacity: 2000 MW (2 x 4 units)
Head: 2 x 600 m, (two drops)
Storage: 10 hours
Units: Single Stage Reversible

UNDERGROUND PUMPED STORAGE
CONSTRUCTION SCHEDULE
(WITH ANNUAL DISBURSEMENTS)

ITEM	Total Cost $1000 / Year	1	2	3	4	5	6	7	8
Mobilization	35,735	35,735							
Access Shafts and Penstock Shaft	33,829	3,759	15,035	15,035					
Lower Reservoir Ventilation Shaft	17,265				2,158	8,633	6,474		
Construction Adits and Loading Areas	5,770		1,538	1,539 1,155	1,538				
Intermediate Reservoir	10,044					1,674	6,696	1,674	
Lower Reservoir	159,674				34,216	45,621	45,621	34,216	
Powerhouse Excavation	16,091				8,939	7,152			
Powerhouse Concrete & Other Concrete	49,565					20,409	23,325	5,831	
Main Equipment Installation	90,620						39,187	39,187	12,246
Auxiliary Equipment Installation	39,695						16,539	17,643	5,513
Testing and Commercial Operation	CONTRACT AWARD							T_1	T_2 T_3 T_4 C_1 C_2 C_3 C_3
Upper Reservoir Bridges, and Roads	27,331				8,199	10,939	8,199		
SUBTOTAL DIRECT COST	485,619	39,494	16,573	17,729	55,050	94,428	146,041	98,551	17,759
Contingencies Civil Underground 25%	77,989		3,899	3,900	7,799	11,698	11,698	15,598	23,397
Contingencies Civil Above Ground 15%	7,110					1,422	3,555	2,133	
Contingencies Equipment 10%	13,032					1,303	3,909	3,910	3,910
SUBTOTAL CONTINGENCIES	98,131		3,899	3,900	7,799	14,423	19,162	21,641	27,307
SUBTOTAL									
ENGINEERING SUPERVISION & OVERHEAD 12%	49,375	3,950	3,950	4,937	7,900	7,900	7,900	7,900	4,938
TOTAL	633,125	43,444	24,422	26,566	70,749	116,751	173,103	128,092	50,004

NOTES

Land was assumed bought before the Award of Civil Contract.

30% of Engineering and Overhead was assumed spent before construction started.

$25,211,000 considered spent before construction started.

T_n - start test on unit "n"

C_n - commercial operation of unit "n".

MAIN

BUREAU OF RECLAMATION

DEPARTMENT OF ENERGY

SCHEME III: Capacity: 2000 MW (6 units)
Head: 1200 m, (one drop)
Storage: 10 hours
Units: Tandem

UNDERGROUND PUMPED STORAGE
CONSTRUCTION SCHEDULE
(WITH ANNUAL DISBURSEMENTS)

ITEM	Total Cost $1000 \ Year	1	2	3	4	5	6	7	8
Mobilization	52,017	52,017							
Access Shafts and Penstock Shaft	32,669	3,630	14,520	14,519					
Lower Reservoir Ventilation Shaft	9,737				2,434	4,869	2,434		
Construction Adits and Loading Areas	3,920			3,920					
Intermediate Reservoir	———								
Lower Reservoir	145,392				41,541	41,541	41,540	20,770	
Powerhouse Excavation	11,886			1,698	10,188				
Powerhouse Concrete & Other Concrete	43,000				3,308	19,846	19,846		
Main Equipment Installation	158,610					19,225	57,676	57,676	24,038
Auxiliary Equipment Installation	35,607					3,338	13,353	13,353	5,563
Testing and Commercial Operation								T_1 T_2 C_1 T_3 C_2	T_4 C_3 T_5 C_4 T_6 C_5 C_6
Upper Reservoir Bridges, and Roads	27,331				9,111	9,110	9,110		
SUBTOTAL DIRECT COST	520,169								
Contingencies Civil Underground 25%	70,138		3,507	3,507	7,014	10,521	10,521	14,027	21,041
Contingencies Civil Above Ground 15%	7,110					1,422	3,555	2,133	
Contingencies Equipment 10%	19,422					1,942	5,827	5,827	5,826
SUBTOTAL CONTINGENCIES	96,670		3,507	3,507	7,014	13,885	19,903	21,987	26,867
SUBTOTAL									
ENGINEERING SUPERVISION & OVERHEAD 12%	51,983	4,158	4,159	5,198	8,317	8,317	8,318	8,318	5,198
TOTAL	668,822	59,805	22,186	28,842	81,913	120,131	172,180	122,104	61,661

CONTRACT AWARD (marked at Main Equipment Installation)

NOTES

Land was assumed bought before the Award of Civil Contract.

30% of Engineering and Overhead was assumed spent before construction started.

$24,278,000 considered spent before construction started.

T_n - start test on unit "n"

C_n - commercial operation of unit "n".

MAIN

BUREAU OF RECLAMATION

DEPARTMENT OF ENERGY

UNDERGROUND PUMPED STORAGE

CONSTRUCTION SCHEDULE

(WITH ANNUAL DISBURSEMENTS)

SCHEME IV: Capacity: 2000 MW (6 units)
Head: 1500 m, (one drop)
Storage: 10 hours
Units: Multi Stage Reversible

ITEM	Year / Total Cost $1000	1	2	3	4	5	6	7	8
Mobilization	46,693	46,693							
Access Shafts and Penstock Shaft	41,143	3,982	15,926	15,926	5,309				
Lower Reservoir Ventilation Shaft	12,500					5,000	5,000	2,500	
Construction Adits and Loading Areas	3,920				3,920				
Intermediate Reservoir	—								
Lower Reservoir	119,184				17,026	40,863	40,863	20,432	
Powerhouse Excavation	10,266				5,133	5,133			
Powerhouse Concrete & Other Concrete	35,075					9,443	16,189	9,443	
Main Equipment Installation	136,800						42,750	51,300	42,750
Auxiliary Equipment Installation	37,047						10,755	14,341	11,951
Testing and Commercial Operation									T_1 T_2 T_3 T_4 T_5 T_6 / C_1 C_2 C_3 C_4 C_5 C_6
Upper Reservoir Bridges, and Roads	24,298				3,472	10,413	10,413		
SUBTOTAL DIRECT COST	466,926	50,675	15,926	15,926	34,860	70,852	125,970	98,016	54,701
Contingencies Civil Underground 25%	63,520		3,176	3,176	6,352	9,528	9,528	12,704	19,056
Contingencies Civil Above Ground 15%	6,135					1,227	3,068	1,840	
Contingencies Equipment 10%	17,385					1,739	5,215	5,216	5,215
SUBTOTAL CONTINGENCIES	87,040		3,176	3,176	6,352	12,494	17,811	19,760	24,271
SUBTOTAL									
ENGINEERING SUPERVISION & OVERHEAD 12%	46,693	3,735	3,736	4,669	7,471	7,471	7,471	7,471	4,669
TOTAL	600,659	54,410	22,833	23,771	48,683	90,817	151,252	125,247	83,641

CONTRACT AWARD

NOTES

Land was assumed bought before the Award of Civil Contract.

30% of Engineering and Overhead was assumed spent before construction started.

$21,911,000 considered spent before construction started.

T_n - start test on unit "n"

C_n - commercial operation of unit "n".

MAIN

BUREAU OF RECLAMATION

DEPARTMENT OF ENERGY

SCHEME V: *Capacity*: 2000 MW (6 units)
Head: 900 m, (one drop)
Storage: 10 hours
Units: Multi Stage Reversible

UNDERGROUND PUMPED STORAGE
CONSTRUCTION SCHEDULE
(WITH ANNUAL DISBURSEMENTS)

ITEM	Total Cost $1000 / Year	1	2	3	4	5	6	7	8	9
Mobilization	52,353	52,353								
Access Shafts and Penstock Shaft	28,384	4,055	16,219	8,110						
Lower Reservoir Ventilation Shaft	8,373				2,392	4,785	1,196			
Construction Adits and Loading Areas	3,920			3,920						
Intermediate Reservoir	———									
Lower Reservoir	196,766			10,931	43,726	43,726	43,726	43,726	10,931	
Powerhouse Excavation	11,360				7,303	4,057				
Powerhouse Concrete & Other Concrete	37,453					11,236	14,981	11,236		
Main Equipment Installation	119,400						30,703	40,937	40,937	6,823
Auxiliary Equipment Installation	33,197						7,811	11,717	11,717	1,952
Testing and Commercial Operation	CONTRACT AWARD								T_1 T_2 T_3 T_4 C_1 C_2 C_3	T_5 T_6 C_4 C_5 C_6
Upper Reservoir Bridges, and Roads	32,320				2,486	9,945	9,945	9,944		
SUBTOTAL DIRECT COST	523,526	56,408	16,219	22,961	55,907	73,749	108,362	117,560	63,585	8,775
Contingencies Civil Underground 25%	78,727		3,936	3,936	7,873	11,809	11,809	15,745	19,682	3,937
Contingencies Civil Above Ground 15%	8,733					1,746	4,367	2,620		
Contingencies Equipment 10%	15,260					1,526	4,578	4,578	4,578	
SUBTOTAL CONTINGENCIES	102,720		3,936	3,936	7,873	15,081	20,754	22,943	24,260	3,937
SUBTOTAL										
ENGINEERING SUPERVISION & OVERHEAD 12%	52,789	4,223	4,224	5,279	8,446	8,446	8,446	8,446	4,224	1,055
TOTAL	679,035	60,631	24,379	32,176	72,226	97,276	137,562	148,949	92,069	13,767

NOTES

Land was assumed bought before the Award of Civil Contract. 30% of Engineering and Overhead was assumed spent before construction started.

$24,824,000 considered spent before construction started.

T_n - start test on unit "n"

C_n - commercial operation of unit "n".

MAIN

BUREAU OF RECLAMATION

DEPARTMENT OF ENERGY

SCHEME VI: Capacity: 2700 MW (8 units)
Head: 1200 m, (one drop)
Storage: 10 hours
Units: Multi Stage Reversible

UNDERGROUND PUMPED STORAGE CONSTRUCTION SCHEDULE (WITH ANNUAL DISBURSEMENTS)

ITEM	Total Cost $1000	Year 1	2	3	4	5	6	7	8	9	10
Mobilization	60,918	60,918									
Access Shafts and Penstock Shaft	36,144	4,016	16,064	16,064							
Lower Reservoir Ventilation Shaft	11,050				2,762	5,525	2,763				
Construction Adits and Loading Areas	3,920			3,920							
Intermediate Reservoir	———										
Lower Reservoir	200,442				42,952	42,952	42,952	42,951	28,635		
Powerhouse Excavation	12,740			1,416	8,493	2,831					
Powerhouse Concrete & Other Concrete	48,066					13,518	18,025	16,523			
Main Equipment Installation	159,610						17,101	45,603	45,603	45,603	5,700
Auxiliary Equipment Installation	44,150	CONTRACT AWARD					3,311	13,245	13,245	13,246	1,103
Testing and Commercial Operation									T_1 T_2 T_3 C_1 C_2	T_4 T_5 T_6 T_7 C_3 C_4 C_5 C_6	T_8 C_7 C_8
Upper Reservoir Bridges, and Roads	32,138					10,713	10,713	10,712			
SUBTOTAL DIRECT COST	609,178	64,934	16,064	21,400	54,206	75,539	94,865	129,034	87,483	58,849	6,803
Contingencies Civil Underground 25%	86,595		4,331	4,331	8,659	8,659	8,659	12,989	12,989	12,989	12,989
Contingencies Civil Above Ground 15%	9,186					919	1,837	2,756	1,837	1,837	
Contingencies Equipment 10%	20,376							2,038	6,113	6,113	6,112
SUBTOTAL CONTINGENCIES	116,157		4,331	4,331	8,659	9,578	10,496	17,783	20,939	20,939	19,101
SUBTOTAL											
ENGINEERING SUPERVISION & OVERHEAD 12%	61,113	4,278	4,278	4,889	6,111	6,111	6,111	7,333	7,334	7,334	7,334
TOTAL	786,448	69,212	24,673	30,620	68,977	91,228	111,472	154,150	115,756	87,122	33,238

NOTES:

Land was assumed bought before the Award of Civil Contract. 30% of Engineering and Overhead was assumed spent before construction started.

$23,391,000 considered spent before construction started.

T_n - start test on test on unit "n"

C_n - commercial operation of unit "n".

MAIN

BUREAU OF RECLAMATION

DEPARTMENT OF ENERGY

SCHEME VII: Capacity: 1300 MW (4 units)
Head: 1200 m, (one drop)
Storage: 10 hours
Units: Multi Stage Reversible

UNDERGROUND PUMPED STORAGE
CONSTRUCTION SCHEDULE
(WITH ANNUAL DISBURSEMENTS)

ITEM	Total Cost $1000 / Year	1	2	3	4	5	6	7	8
Mobilization	33,826	33,826							
Access Shafts and Penstock Shaft	32,742	3,778	15,112	13,852					
Lower Reservoir Ventilation Shaft	10,450				1,306	5,225	3,919		
Construction Adits and Loading Areas	3,920			3,920					
Intermediate Reservoir	———								
Lower Reservoir	98,698			26,918	35,890	35,890			
Powerhouse Excavation	7,282			1,214	6,068				
Powerhouse Concrete & Other Concrete	24,083				4,188	12,565	7,330		
Main Equipment Installation	81,910 (CONTRACT AWARD)					20,478	35,104	26,328	
Auxiliary Equipment Installation	23,880					5,307	10,613	7,960	
Testing and Commercial Operation								T_1 T_2 C_1 T_3 C_2 T_4 C_3 T_5 C_4	
Upper Reservoir Bridges, and Roads	21,473				2,684	10,737	8,052		
SUBTOTAL DIRECT COST	338,264	37,604	15,112	18,986	41,164	90,202	100,908	34,288	
Contingencies Civil Underground 25%	49,688	2,484	4,969	9,938	9,938	9,937	12,422		
Contingencies Civil Above Ground 15%	5,343				1,069	2,671	1,603		
Contingencies Equipment 10%	10,579				1,058	3,173	3,174	3,174	
SUBTOTAL CONTINGENCIES	65,610	2,484	4,969	9,938	12,065	15,781	17,199	3,174	
SUBTOTAL									
ENGINEERING SUPERVISION & OVERHEAD 12%	34,085	4,431	4,431	5,454	5,454	5,454	5,453	3,408	
TOTAL	437,959	44,519	24,512	34,378	58,683	111,437	123,560	40,870	

NOTES

Land was assumed bought before the Award of Civil Contract.
30% of Engineering and Overhead was assumed spent before construction started.
$16,508,000 considered spent before construction started.
T_n - start test on unit "n"
C_n - commercial operation of unit "n".

MAIN

APPENDIX IV

DR. RONALD C. HIRSCHFELD'S REPORT

GEOTECHNICAL ENGINEERS INC.
1017 MAIN STREET · WINCHESTER · MASSACHUSETTS 01890 (617) 729-1625

PRINCIPALS
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ASSOCIATES
CHARLES E. OSGOOD
BARTLETT W. PAULDING, JR

May 5, 1977
Project 77332
File No. 2.0

Charles T. Main, Inc.
Southeast Tower
Prudential Center
Boston, MA 02199

Attention: Mr. Mircea S. Vasilescu

Subject: Underground Pumped Storage Research

Gentlemen:

At the request of Mr. Vasilescu I have made a brief review of the prospects for technological and other developments that might have a significant impact on the cost of underground rock excavation 10 to 15 years from now.

Based on this review, it is my opinion that the cost index for underground rock excavation for pumped storage will change approximately the same as the cost indices for other types of heavy construction in non-urban areas (excluding earthmoving) during the next 10 years.

This opinion is based on my personal experience, discussions with engineers involved in construction, government agencies, and universities, and a very brief literature review.

The following factors are the basis for the above opinion:

1. During the past 10-15 years, the cost of tunneling has increased at more or less the same rate as the cost of other types of heavy construction. This implies that technological and other advances during that period, when research and development were proceeding at a high level, did not result in greater efficiency in underground rock excavation than in other types of non-urban heavy construction. Considering the slowdown in the rate of research on

rock excavation (see 2. and 3. below) it appears unlikely that research during the next 10 to 15 years would alter the trend of increasing cost of the past 10 years.

2. Sponsorship of some research on underground rock excavation has been abandoned by individual agencies in favor of other research that is expected to yield greater return.

3. The National Science Foundation, which is currently sponsoring research on underground excavation of rock, has experienced a substantial decrease in the number of proposals received for research in this area, an indication that researchers are not optimistic about the potential for achieving "breakthroughs."

4. Many of the "exotic" methods of rock excavation that have been studied have proven to be technologically or economically infeasible. The most promising of those methods appear to be just barely competitive with conventional methods with respect to cost.

5. Underground contractors have not made use of the proposed "exotic" techniques, as they surely would if those techniques could reduce the cost of underground rock excavation.

6. Tunnel boring machines which have captured a substantial market for underground rock excavation have proven to be substantially cheaper only for cases in which the rock conditions are ideally suited to machine tunneling (e.g., sound shales). On large projects that involve several tunneling contracts in essentially similar rock conditions (such as the Washington subway) drilling-and-blasting and machine-borings each capture a share of the work which indicates that neither has a clearcut economic advantage over the other.

7. One new technique, a tunnel-boring machine assisted by high-pressure water jets, has been used on an experimental basis in the field, is being developed commercially in Germany for coal mining, and is under consideration by machine manufacturers and tunneling contractors

today. The field experiment did encounter technical problems which may or may not be resolved so that the technique will become commercially viable. The maximum increase of advance rate measured in the field experiment was about 100%, and the average rate about 50% when the equipment was operating satisfactorily. (From a theoretical analysis, the researchers concluded that a 50% increase in advance rate would correspond to approximately a 25% decrease in cost for an assumed 20-foot-diameter tunnel in 25,000 psi rock for a hydroelectric project in Wyoming, Utah, and Colorado.)

Although it is possible that an unanticipated advance in technology could significantly affect the cost of underground rock excavation within the next 10 years, it is my opinion that there will be no "revolutionary" changes, only "evolutionary" improvements similar to those which have taken place in the past 10 to 15 years.

Sincerely yours,
GEOTECHNICAL ENGINEERS INC.

Ronald C. Hirschfeld

Ronald C. Hirschfeld
President

RCH:ms

APPENDIX V

CREDITS

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CREDITS

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The Argonne National Laboratories, acting on behalf of DOE monitored the technical activities involved in this inter-agency agreement.

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Dr. Ronald G. Hirschfeld was an individual consultant for technical developments impacting on underground rock excavation costs.