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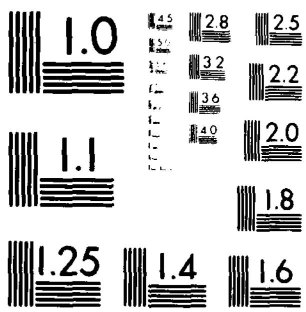

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NAVAL CONSTRUCTION BATTALION CENTER
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The sea/lake water air conditioning (AC) work at CEL and related efforts by others are summarized, along with annotated references. Computer models for estimating the capital costs and energy use for sea/lake water air conditioning (AC) systems are introduced, and the output from these models exercised on two Naval facilities are presented. It was found that (1) the computer models produced reasonable estimates of the capital cost and

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energy use of seawater AC systems; (2) the capital cost and energy use of such systems are sensitive to the pipeline length, which is dependent on the seawater temperature near the seafloor; (3) at a hypothetical typical Naval facility represented by the average of the two trial facilities, seawater AC requires 80% less energy than conventional AC, but the capital cost of seawater AC is 60% greater; and (4) at this typical facility the life cycle cost for seawater AC is 25% less than that of conventional AC. Sea/lake water AC is recommended for consideration as an alternative to conventional AC at Naval facilities that adjoin bodies of water, and it is also recommended that the computer models be used to make estimates of the capital cost and energy use of sea or lake water AC systems.

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SEA/LAKE WATER AIR CONDITIONING AT NAVAL FACILITIES (Final), by J. B. Ciani
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The sea/lake water air conditioning (AC) work at CEL and related efforts by others are summarized, along with annotated references. Computer models for estimating the capital costs and energy use for sea/lake water air conditioning (AC) systems are introduced, and the output from these models exercised on two Naval facilities are presented. It was found that (1) the computer models produced reasonable estimates of the capital cost and energy use of seawater AC systems; (2) the capital cost and energy use of such systems are sensitive to the pipeline length, which is dependent on the seawater temperature near the seafloor; (3) at a hypothetical typical Naval facility represented by the average of the two trial facilities, seawater AC requires 80% less energy than conventional AC, but the capital cost of seawater AC is 60% greater; and (4) at this typical facility the life cycle cost for seawater AC is 25% less than that of conventional AC. Sea/lake water AC is recommended for consideration as an alternative to conventional AC at Naval facilities that adjoin bodies of water, and it is also recommended that the computer models be used to make estimates of the capital cost and energy use of sea or lake water AC systems.

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CONTENTS

INTRODUCTION

While the demand for air conditioning (AC) at Naval facilities has stabilized, the cost of power has grown tremendously in recent years, and the availability of power plant fuel from the traditional domestic sources has declined sharply. Therefore, alternatives to the high power consuming AC systems are being sought. The Civil Engineering Laboratory (CEL) under the sponsorship of the Naval Material Command and the Naval Facilities Engineering Command has investigated the use of naturally cold sea or lake water as an alternative cooling and dehumidification medium for Naval facilities.

This report provides: (1) a summary of the work accomplished by CEL on sea/lake water AC for Naval facilities; (2) a description of the computer models developed to estimate the capital cost and energy use of such AC; (3) the results obtained by applying these models to two Naval facilities (Pacific Missile Test Center (PMTC) Point Mugu, Calif., and Naval Shipyard (NSY) Pearl Harbor, Hawaii); (4) the results of an analysis to determine the sensitivity of capital cost and energy use of seawater AC at these facilities to the seawater intake location and water temperature; and (5) the life cycle cost (LCC) of such AC systems compared to the LCC of conventional AC.

SEA/LAKE WATER AC INVESTIGATIONS

At CEL the development effort on sea/lake water AC for Naval facilities included an assessment of the feasibility of sea/lake water cooling, the design of an operational test at Naval Security Group Activity (NSGA) Winter Harbor, Me., and the economics of Navywide application.

In FY76 an assessment of the feasibility of seawater cooling for Naval facilities was made. It was found that there is potential for cost and energy savings with this type of AC (Ref 1). The design of an operational test system for NSGA followed. Surveys there found that a small (84 tons refrigeration (TR)) seawater cooling system could be installed and operated at this facility at a lower LLC than a conventional AC system, but the control of biofouling in such a seawater cooling system at this site posed a problem that needed solving before implementation could be made (Ref 2 through 8). Assessments of the economics of Navywide application of sea/lake water AC indicated that cost and energy savings at the sites of some Naval facilities are possible, depending on the temperature in the adjoining water bodies, but that biofouling control and required maintenance remain risk issues (Ref 9 through 12).

CEL has not been alone in examining the use of natural waters for AC. In related work, AC with seawater off Florida, California, or Hawaii, or lake water from Lake Michigan, or well water in New Jersey has been found technically and economically feasible and can save energy (Ref 13 through 18).

ECONOMICS AT TWO FACILITIES

Facilities

In FY78, several sites of Naval facilities were identified as having high potential for the cost-effective application of sea/lake water AC (Ref 9). These findings were based on estimates of the energy demand at Naval facilities at these sites and the temperature of the sea or lake water in the adjoining water bodies. In FY79, water temperature measurements were made at two of these sites, Pearl Harbor and Point Mugu, which were determined to have the highest potential among the sites (Ref 12). The choice of specific Naval facilities at these two sites – the Naval Shipyard (NSY) Pearl Harbor and the Pacific Missile Test Center (PMTC) Point Mugu – was based on proximity to the cold water source and requirement for AC.

Comfort cooling is the primary reason for AC at NSY, where three buildings were selected for evaluation (Bldg 1, Bldg 3A, and Bldg 214). The required AC of these buildings is 192 TR, 138 TR, and 205 TR, respectively. Cooling for computers is the primary reason for AC at PMTC where three buildings (Bldg 761, Bldg 50, and Bldg 53) require AC of 465 TR, 255 TR, and 374 TR, respectively. The locations of these buildings are shown in Figures 1 and 2.

Estimates were made of the capital costs and energy use of seawater AC at these two facilities using computer models. These estimates compared well with the preliminary estimates given in Reference 9.

Computer Models

Mathematical models were developed for estimating the capital costs and energy usage in sea or lake water AC systems. The following models were developed to make these estimates:

1. Cold Water Supply Model – two computer programs were required, one for the offshore portion of the system (program IA) and one for the onshore portion (program IB) (Ref 10).

2. AC Equipment Model – only one computer program (program II) was required (Ref 11).

These programs were written such that the amount of site data and preliminary design assumptions required for input to the programs could be varied, depending on the level of detail in the available data and the level of expertise of the program operators in AC system and pipeline design. As a minimum, the data required for input to these programs are: (1) the temperature/distance from shore profile data for program IA, (2) estimates of land pipe inside diameter and length of sections for program IB, and (3) location and building parameters for program II. Of the three types of data required, item (2) can be easily estimated by anyone with a basic knowledge of pipeline design, and item (3) can be obtained from several commonly available handbooks. However, item (1) is not as readily available because it is based on water temperature data at the site for the time of the year when the water is warmest. Consequently, a special water temperature survey would probably be required at any specific site.

The site data and design assumptions made in these programs are given in References 10 and 11. It is notable that these design assumptions allow for only one intake pipeline for the cold water supply. Therefore, the computer-generated capital cost estimates for cold water supply must be modified in order to use a two-intake pipeline system. Such a system, which was referred to as three-pipe (inlet-outlet-standby), was recommended by Reference 8. Other biofouling control recommendations given in Reference 8 are fully covered in the computer models. The capital cost estimates made for PMTC and NSY were modified to account for two intake pipelines at these facilities.

Sensitivity

The capital cost and energy use sensitivity of seawater AC to the distance of the seawater intake location from shore and to the intake water temperature is shown in Table 1.* Cost and use data were taken from the output of runs of the computer programs for the two trial facilities.

It is seen from the estimates given in Table 1 that (1) the capital cost is sensitive to the pipeline length which is dependent on the seawater temperature near the seafloor and the distance of the intake from shore, (2) the energy use is also dependent on this distance and temperature, and (3) the ability of any site to support seawater AC depends on the temperature of the seawater at the intake.**

Capital Costs and Energy Use

Table 2 presents the capital costs and energy use of seawater AC at the two trial facilities based on two intake pipelines at a single location at each – PMTC II and NSY III (see Table 1). Similar capital costs and energy use figures are also given in this table for conventional AC. Averages of the estimates of capital costs and energy use for these two facilities are also given and taken to represent values for a hypothetically typical Naval facility. The figures in Table 2 are based on three buildings at each trial facility with a total of 1094 TR at PMTC and 535 TR at NSY. 815 TR for three buildings at a "typical" Naval facility is an average of those of the trial facilities.

By way of a check on how typical the cooling load average is, the AC requirements given in Reference 9 for four sites (Apra Harbor, Guam; Pearl Harbor, Hawaii; Chicago, Ill.; and Point Mugu, Calif.) of Naval facilities (19 facilities) were averaged and found to be 849 TR, which compares favorably with 815 TR.

Life Cycle Costs

The LCC of seawater and conventional AC at the typical Naval facility based on the computer output are given in Table 3 along with the differential LCC (i.e., conventional AC LCC minus seawater AC LCC). The

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*Intake locations are designated by I, II, or III.

**With the intake seawater temperature values given in Table 1, it appears that 50°F is an upper limit for sea/lake water AC.

estimates of the capital cost of biofouling control equipment and annual maintenance costs included in this LCC are based on the estimates given in Reference 2 for NSGA Winter Harbor and corrected for the much larger AC tonnage at the typical Naval facility.

The sensitivity of the total LCC to a 100% increase in the estimated cost of biofouling control equipment and a 100% increase in the estimated annual cost of operation and maintenance (not including electricity) is only 15%. Consequently, there appears to be little need to improve these estimates.

FINDINGS

1. The computer models described in this report provided reasonable estimates of the capital cost and energy use of seawater AC systems at Point Mugu and Pearl Harbor.

2. The capital cost and energy use of seawater AC systems for the trial facilities are sensitive to the pipeline length, which is dependent on the seawater temperature near the seafloor versus the distance from shore at the sites.

3. At Point Mugu, seawater AC would use 80% less energy than conventional AC; at NSY Pearl Harbor, 70% less. The capital cost of seawater AC at PMTC is about equal to that of conventional AC, but at NSY the capital cost of seawater AC is three times greater than conventional AC. Therefore, though substantial energy savings are possible at both trial facilities, the capital cost of seawater AC is at least as much as conventional AC.

4. At a hypothetical typical Navy facility, seawater AC will use 80% less energy than conventional AC, but the capital cost of sea/lake water AC is 60% greater. The LCC of seawater AC at a typical Naval facility is 25% lower than the LCC of conventional AC.

RECOMMENDATIONS

1. Sea/lake water AC should be considered as an energy and LCC saving alternative to conventional AC at Naval facilities which adjoin bodies of water.

2. The computer models introduced in this report should be used to make estimates of the capital cost and energy use of sea or lake water AC systems.

3. No further research and development on sea/lake water AC is recommended.

ACKNOWLEDGMENTS

The author wishes to thank Robert Okazaki of the Public Works Office at the Naval Shipyard Pearl Harbor and Robert Owens of the Pacific Missile Test Center Point Mugu for information on their respective Naval facilities and AC requirements there. Thanks are also in order to Nathan Shoemaker of the Civil Engineering Laboratory for his help in running the sea/lake water AC models.

REFERENCES (ANNOTATED)

1. Civil Engineering Laboratory. Technical Memorandum M-44-76-10: Seawater cooling for Naval facilities, by J. B. Ciani and A. W. McClaine. Port Hueneme, Calif., Aug 1976.

This feasibility assessment of seawater cooling showed that this type of air conditioning has potential for cost and energy savings at Naval facilities.

2. __________. Contract Report 78.008: A preliminary design, economic and energy analysis, and environmental impact assessment for a seawater cooling project, Naval Security Group Facilities at Winter Harbor, Maine, final report. Port Everglades, Fla., Tracor Marine, Mar 1977. (Contract No. N68305-77-C-0012)

This report provides tentative design, analysis, and specifications for a seawater cooling (AC) system which is the first of its kind.

3. __________. A review and analysis of the economic life cycle cost analysis of the final report by Tracor Marine on the seawater cooling project Naval Security Group Facilities at Winter Harbor, Maine. Laguna Beach, Calif., Malcolm Lewis Associates, Sep 1977. (Contract No. N62583-77-M-R632)

This report reviewed the economic analysis of Reference 2 and found that although the analysis technique used by Tracor is not strictly correct, it is true that for this facility the life cycle costs of seawater cooling are lower than those for conventional AC.

4. Naval Facilities Engineering Command, Northern Division. Energy and economic analysis of the heating, ventilating, and air conditioning systems and modifications to the systems to make them more energy efficient at Navy operations Building #153 Naval Security Group Activity, Winter Harbor, (Corea) Maine, by M. Flanders and C. Braley. Bangor, Me., Webster, Ebbeson, Baldwin and Day, Architects, Sep 1977. (Contract No. N62472-76-C-1101)

This investigation of the AC systems at NSGA Winter Harbor and six modifications, of which seawater cooling is one, to these systems to make them more energy efficient found that none of the modifications are economically justified but that (1) the life cycle cost of the seawater cooling system is much less than that of the existing systems or any of the modifications, (2) in a new building at Winter Harbor seawater cooling would be more economical than conventional AC, and (3) in a building with a much larger cooling load than that at NSGA Winter Harbor the installation of a seawater cooling system might be justified even if there exists a working AC system.

5. Civil Engineering Laboratory. Contract Report 78.009: Supplements no. 1 and no. 2 to a preliminary design, economic and energy analysis, and environmental impact assessment for a seawater cooling project, Naval Security Group Facilities at Winter Harbor, Maine (CR 78.008), Supplement no. 1: Bottom temperature measurements in Prospect Harbor, Supplement no. 2: Biofouling and its prevention in Prospect Harbor. Port Everglades, Fla., Tracor Marine, Nov 1977. (Contract No. N68305-77-C-0012)

Supplement 1 reports on the measurement of the temperature of the seawater near the bottom of the bay that adjoins Winter Harbor and found that the bottom water temperature is such that it will support seawater cooling at NSGA Winter Harbor through nine months of the year but that AC enhancement is required during the three warmest months.

Supplement 2 reports on biofouling in a seawater cooling system at Winter Harbor (Ref 5, Supplement no. 2) which concluded that such a system must cope with a serious biofouling problem whose most economical solution is a seawater well sunk into the bottom sediments or an infiltration gallery on the seafloor whose surface is cleaned by wave action provided such a well or gallery can support the required flow (permeability).

6. __________. Report of inspection and pipeline route survey (including land and offshore portions) for a seawater cooling project Naval Security Group Facilities Winter Harbor, Maine. Port Everglade, Fla., Tracor Marine, Nov 1977. (Contract No. N62583/77 M R620 and N62583/77 M R734)

This is a report of the selection/survey of the seawater intake pipeline route on land and on the seafloor which selected and inspected the route, measured the topography and bathymetry, probed the sediment, and took cores.

7. __________. Feasibility study and preliminary design for an offshore seawater intake well and/or infiltration gallery/bed for a seawater cooling system USNSGA, Corea, Maine. Port Everglades, Fla., Tracor Marine, May 1979. (Contract No. N62583-79-M-R290)

This report assesses the feasibility of a seawater well or an infiltration gallery for the intake of seawater for cooling at NSGA Winter Harbor (Ref 7) and concludes that such a well or gallery is not practical at this site but may be useful for seawater cooling systems elsewhere.

8. __________. Technical Memorandum M-52-79-03: Possible methods for the control of fouling of seawater cooling systems, by T. Roe, Jr. Port Hueneme, Calif., Jul 1979.

This report discusses biofouling control methods for seawater cooling systems and identifies twelve such methods; the advantages and disadvantages of each are given. This report recommended that:

(1) The heat exchangers for a seawater cooling system be made of 90:10 copper nickel alloy

(2) A three-pipe, inlet-outlet-standby system (two intakes and one outlet) be used for influent and effluent

(3) Rigid thermoplastics or glass reinforced thermosetting pipe be used for the offshore pipelines

9. __________. Technical Note N-1528: Sea/lake water cooling for Naval facilities, by J. B. Ciani. Port Hueneme, Calif., Sep 1978.

This report assesses the Navywide potential of sea or lake water AC and found that $3 million per year could be saved if this new type of AC were in operation at Naval facilities at 25 sites. These include four sites (Apra Harbor, Guam; Pearl Harbor, Hawaii; Chicago, Ill.; and Point Mugu, Calif.) where $1 million per year could be saved.

10. __________. A computer model for estimating costs and energy usage for air conditioning systems using natural cold water, final report. Port Everglades, Fla., Tracor Marine, Mar 1979. (Contract No. N62583-78-M-R683)

This report describes a computer model for cold water supply to sea/lake water cooling (AC) systems. This model provides a set of computer programs that can be used to estimate the capital cost of a single intake and the energy required to supply sea or lake water to such an AC system at any facility. Another output of this program is the temperature of the water delivered to the sea/lake water cooling equipment on shore.

11. __________. A computer assisted model for estimating offshore and onshore water supply costs and energy usage for facilities using natural cold water to directly air condition buildings, final report. Port Everglades, Fla., Tracor Marine, Apr 1979. (Contract No. N62583-78-M-R406)

This report describes a computer model for air conditioning by sea/lake water cooling systems which provides a computer program that can be used to estimate the capital cost and energy required to air condition a single building using sea or lake water. An input to this program is the temperature of the water supplied to sea/lake water cooling systems (an output of the cooling water supply model above).

12. __________. Contract Report CR 79.001: Bathythermographic surveys near Naval facilities at Point Mugu, California and Pearl Harbor, Hawaii. La Jolla, Calif., Intersea Research Corporation, May 1979. (Contract No. N68305-78-C-0018)

This report describes the techniques and results of bathythermographic surveys performed at Point Mugu, Calif., and Pearl Harbor, Hawaii, which used existing water temperature data and the measured data to estimate profiles of maximum annual temperatures. These profiles showed that (a) at Point Mugu the maximum annual bottom water temperature can be expected in November at 50°F, 620 feet deep, 1.4 NM offshore and (b) at Pearl Harbor this temperature can be expected in February at 50°F, 1,380 feet deep, 4.0 NM offshore.

13. R. D. Gerard and O. H. Roels. "Deep Ocean Water as a Resource," Marine Technology Society Journal, vol 4, no. 5, Sep-Oct 1970, pp 69-79.

This report suggested the use of seawater off Florida, California, and Hawaii for AC at these sites.

14. Energy Research and Development Administration. Feasibility of a direct seawater cooling system utilizing cold seawater, by J. Hirshman, D. A. Whithaus, and I. H. Brooks. Port Everglades, Fla., Tracor Marine, Jun 1975. (ERDA Contract No. A.T.-(40-1)-4875)

This report presented a study of the feasibility of seawater cooling and concluded that seawater cooling is technically feasible and can result in AC energy savings of over 70%. This study also concluded that Honolulu, Hawaii, and Miami/Ft. Lauderdale, Fla., are sites which are suitable for concept development.

15. __________. District heating and cooling utilizing temperature differences of local waters, by W. Harrison, A. A. Frigo, G. T. Kartsounes, D. J. Santini, S. J. LaBelle, and F. H. Davis. Argonne, Ill., Argonne National Laboratory, May 1977. (ERDA Contract ANL/WR-77-1)

Harrison et al. investigated the use of cold water from Lake Michigan and heated water effluent from a power plant onshore with a heat pump system to provide cooling and heating in Chicago. They concluded that such a system was technically and economically feasible.

16. __________. Feasibility of a direct cooling system using natural cold waters, by J. Hirshman and R. H. Kirklin. Port Everglades, Fla., Tracor Marine, Aug 1977. (ERDA Report No. OMO-4875-B)

This study and preliminary design is of a seawater cooling system for Miami Beach which concluded that such a system is far more economically attractive than conventional AC. These authors also considered the use of naturally cold fresh water in the United States for AC. They concluded that the water in the Great Lakes has potential for direct cooling, the ground water in the northern and mountain states also has potential, but that in the southern states is unsuitable, and river water is likewise unsuitable except summer-melt water from streams near large mountains.

17. Naval Air Engineering Center. Study to determine the feasibility of using well water for air conditioning cooling, by J. C. Morris, Jr. Atlantic Highlands, N.J., John C. Morris Associates, Oct 1978. (Contract N62472-78-C-4947)

This study of the potential use of domestic well water to reduce energy consumption in the air conditioning systems in five buildings at Lakehurst concluded that this use is practical in two of the buildings but impractical in the other three.

18. B. E. Liebert, L. R. Berger, H. J. White, J. Moore, W. McCoy, J. A. Berger, and J. Larsen-Basse. "The effects of biofouling and corrosion on heat transfer measurements," Sixth OTEC Conference, 19-22 Jun 1979, Washington, D.C.

This paper presents data from measurements of the amount and rate of biofouling in test sections of heat exchanger tubes like those of the planned Ocean Thermal Energy Conversion (OTEC) system, a system with many of the same biofouling problems as seawater cooling systems. Mechanical cleaning with a spinning brush was found to reduce biofouling in these tube sections. This work will continue in OTEC experiments and may lead to a biofouling control system which can be applied to sea/lake water AC systems.

Table 1. Sensitivity Analysis

Pipeline Location	Intake Seawater Temperature (°F)	Intake Distance From Shore (ft x 10^3)	Total Capital Cost[a] ($ Million)	Energy Use MBtu/yr TR
PMTC I	49.1	8	1.8	1.7
PMTC II	47.3	11	2.1	1.6
PMTC III	45.1	16	2.6	1.7
NSY I	58.6	17	b	b
NSY II	54.1	20	b	b
NSY III	50.4	24	3.2	2.5

[a]Fiscal Year 1979.

[b]The temperature of the seawater reaching the buildings that require AC is not low enough to maintain design room conditions.

Table 2. Capital Costs and Energy Use

Item	Capital Costs in FY79 ($ Million)			Energy Use (MBtu/yr x 10^3)		
	Point Mugu	Pearl Harbor	Typical[a] Naval Facility	Point Mugu	Pearl Harbor	Typical[a] Naval Facility
Seawater AC	2.1	3.2	2.7	1.7	1.3	1.5
Conventional AC	2.2	1.1	1.7	9.3	4.6	7.0
Savings[b]	0.1	-2.1	1.0	7.2	3.3	5.5

[a]"Typical" in this context is intended to mean typical for Naval facilities where sea/lake water AC has high potential.

[b]Savings = conventional AC - seawater AC.

Table 3. Life Cycle Costs

Cost Basis at Typical Naval Facility	Life Cycle Cost ($ x 10^3/MBtu)	
	Seawater AC	Conventional AC
AC Equipment	21	167
Cold Water Supply System	224	0
Biofouling Control Equipment[a]	24	0
Total Capital Contribution	269	167
O&M Costs[b]	39	2
Electricity Costs[c]	75	343
Total O&M Contribution	114	345
Total LCC (Capital and O&M)	383	512
Differential Life Cycle Cost	129	

[a]Assumed to be 10% of the total system (AC plus cold water supply).

[b]Not including electricity.

[c]Per year cost - rather than life cycle cost.

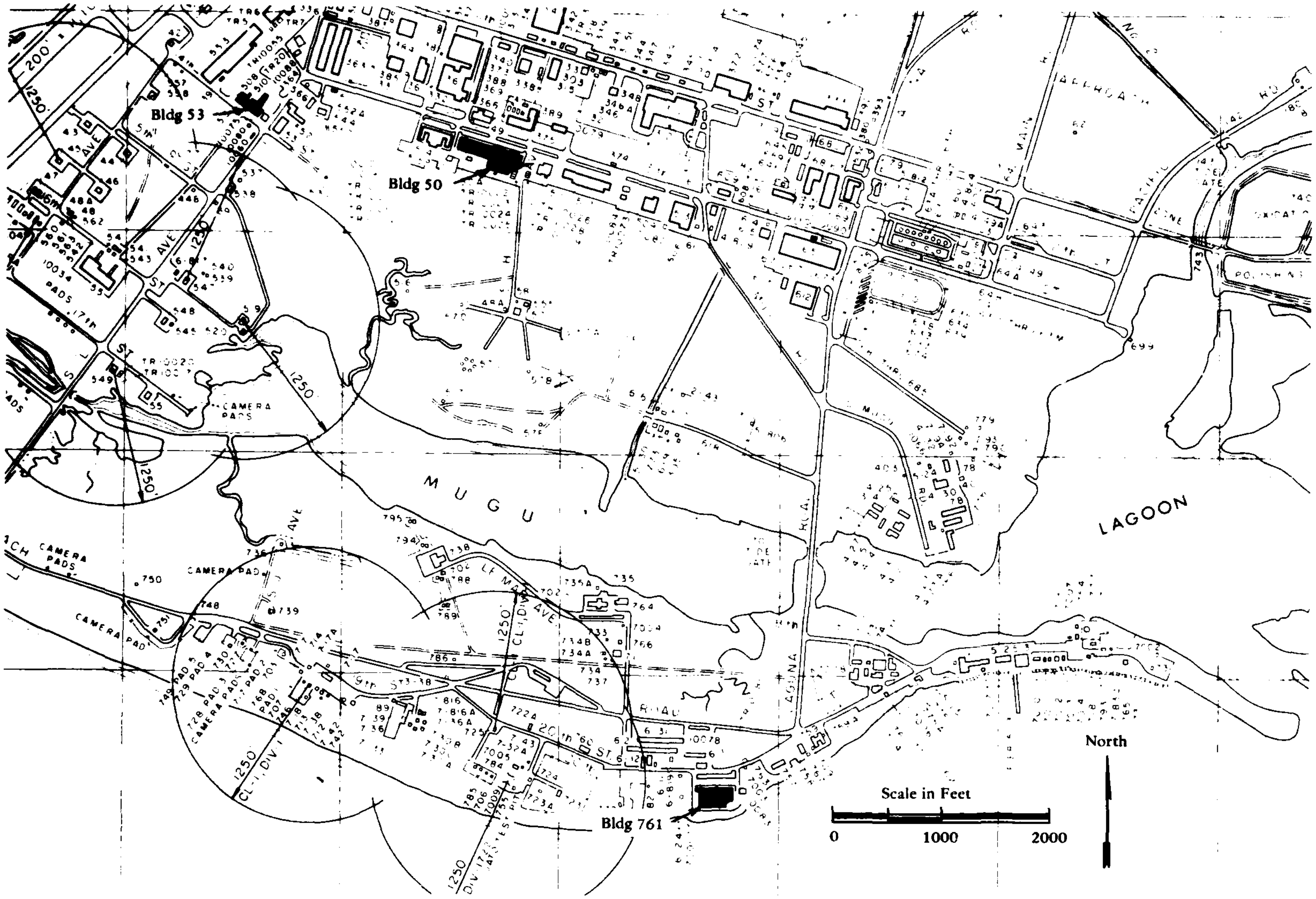

Figure 1. Pacific Missile Test Center, Point Mugu, Calif.

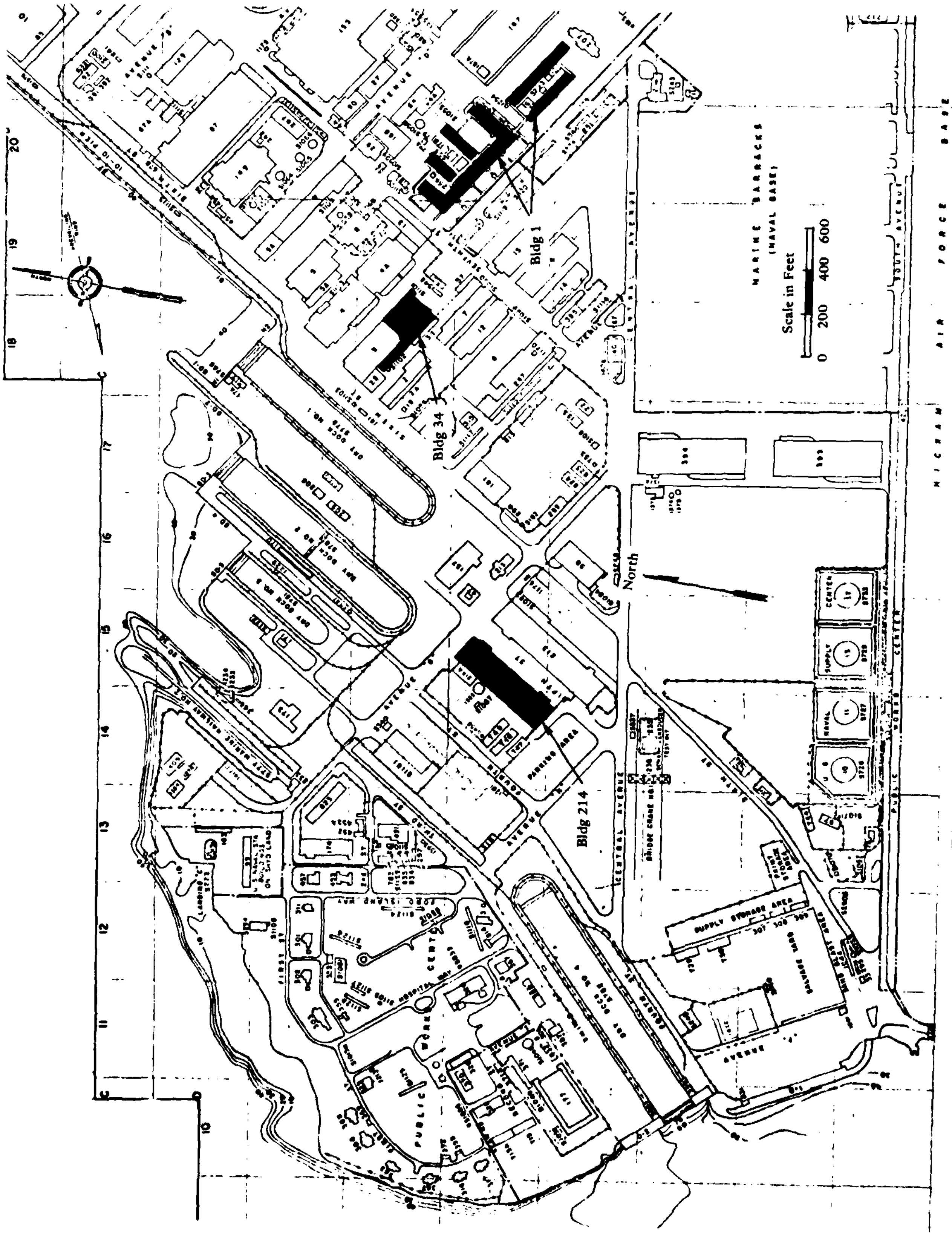

Figure 2. Naval Shipyard, Pearl Harbor, Hawaii.

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