## CHAPTER TWENTY ONE

# US Army Corps of Engineers Field Wave Gaging Program

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## Introduction

While the timely collection and reporting of climatological and environmental data have become routine in many countries, a similar capability for waves, currents, and coastal winds has not. The need for long-term, high quality wave data, in particular, has long frustrated the coastal engineer. In 1974, both Prof. Robert Wiegel and Dean Morrough P. O'Brien commented publically on the need for information on the nearshore wave climate comparable to data routinely available on many other natural phenomena. O'Brien further expressed his concern for improving the accuracy of wave forecasting and hindcasting techniques through comparison with reliable measurements (2).

The need for characterizing the nearshore wave climate is much like the experience of conventional meteorological measurement programs. Along coastlines with high population densities, usage of the resource is intense. Ignorance of the processes at work carries a significant penalty. Past programs either have emphasized the collection of deepwater wave climatology or have been too regional or even site specific. With the Field Wave Gaging Program (FWGP), the US Army Corps of Engineers intends to collect the long-term, nearshore wave data that are necessary for planning, design, construction, operation, and maintenance of coastal projects.

## History and Objectives

In 1974, the American Society of Civil Engineers (ASCE) sponsored a Conference on Ocean Wave Measurement and Analysis. As a direct result of that conference, Scripps Institution of Oceanography installed a regional wave monitoring network for the State of California in 1975. The network began modestly, with only four stations operating by mid-1976, supported by the California Department of Boating and Waterways (Cal Boating) and the National Oceanographic and Atmospheric Administration (NOAA) Sea Grant Program. In 1978, the Corps of Engineers' South Pacific Division (SPD) became involved and provided funding to begin the expansion of this network throughout California. The Coastal Data Information Program (CDIP) became a cooperative effort between the Corps and Cal Boating, with Scripps acting as a contractor for data collection, analysis, and reporting (6).

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Almost concurrently with the formation of the CDIP, the Corps established a nationwide Coastal Field Data Collection Program (CFDCP), one element of which was the FWGP. The goals of the FWGP are to collect nearshore and relatively deepwater wave data to satisfy the immediate needs of the coastal planner, designer, and project operator; to support the Corps' effort to develop a wave hindcast/forecast model; and to provide a long-term data record for all of the nation's coastlines.

In addition to the FWGP, the CFDCP funds efforts to (1) hindcast 20 years of wave information from available wind data in the Atlantic, Gulf of Mexico, and Pacific; (2) identify, catalog, and make available beach profile data already obtained on the US coasts and obtain additional profile data in areas of particular interest; (3) identify, catalog, make available, and continue to update shoreline change maps; (4) continue Littoral Environmental Observations (LEO) in areas of interest; and (5) develop a database management system for the archiving of coastal data that have been and continue to be collected. The CFDCP also provides the mechanism through which valuable coastal data are collected, analyzed, distributed, and archived.

The existence of the CDIP has been very beneficial to the FWGP in two ways: (1) by having begun development on the automated data collection, analysis, and reporting system, and (2) by establishing a network of CDIP gages to provide a starting point from which the national wave gaging system could expand.

## Gage Network

Eventually, the FWGP will acquire wave data along each of the nation's coasts. Primary data for the program will be collected at a number of deepwater, or index sites (Figure 1). These stations will be operated continuously in order to provide reliable long-term statistical wave data for use in planning, design, operation, and maintenance of coastal engineering projects. They are located in water sufficiently deep to minimize bathymetric effects on the measured waves, often as deep as 200 m (650 ft). An additional and unfortunately critical consideration in siting the index gages is to find a location that is not in a commercially fished area. Commercial fishermen using bottom-dragging equipment can break a deepwater mooring with their nets. This is an all too frequent occurrence in commercial fishing grounds even though instruments are reported in the US Coast Guard "Notice to Mariners."

Augmenting the index stations are nearshore gages located in areas generally representative of long stretches of coastline. These nearshore gages are, on occasion, single pressure gages, or, more often, slope arrays. Data are to be collected from these stations for five years to provide the nearshore wave information so necessary to coastal projects and to assist in verification of the numerous wave propagation models. Site selection for slope arrays requires reasonably straight, parallel offshore contours and, like the index stations, consideration of commercial fishing activity. A bottom-mounted sensor can be destroyed by the heavy nets used on large trawlers.

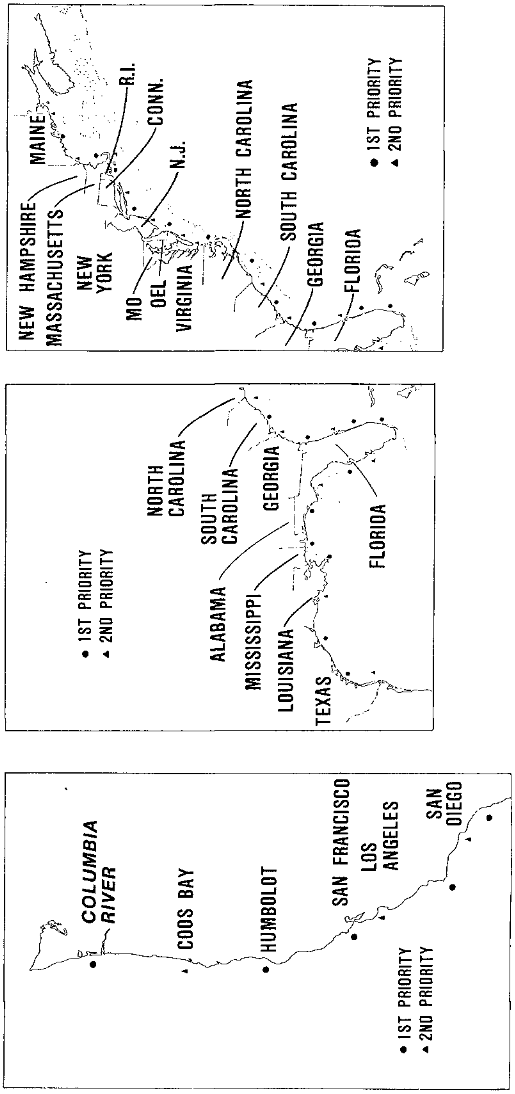


Figure 1. Proposed Index Sites

To date, Datawell Waverider buoys have been used in all of the index station installations; the depth of these installations precludes the use of bottom-mounted sensors. The Waverider buoy is a proven instrument which uses a vertically stabilized accelerometer to sense the vertical component of the buoy's motion. Heave data from the buoy are transmitted up to 50 km (31 miles) to shore.

Nearshore wave measurements, in depths of up to 15 m (50 ft), are made using a bottom-mounted Kulite semiconductor strain gage pressure transducer. The transducer and its circuitry are housed in a plastic pressure case mated to an underwater cable by a plastic underwater connector. The cable is used both to carry the signal ashore and to supply power to the sensor. Sufficient cable is stored in a service loop to allow the sensor housing to be brought to the surface for servicing, thereby increasing the system's reliability (9).

An array of four pressure sensors has been developed by Scripps to obtain directional wave data. This array is 6m (20 ft) square on a side and uses a specially designed armored underwater cable for data and power transmission. This cable has effective abrasion resistance, waterblocking integrity, tensile strength, and resistance to cutting which greatly enhance the system's reliability. Details of the array are described by Seymour and Higgins (8), and results of laboratory and field tests are discussed by Higgins, Seymour, and Pawka (3). Seymour, Domurat, and Pirie (7) describe a test at Santa Cruz, CA, where the estimates of gross and net longshore transport calculated from the array compared favorably with the actual sediment volume dredged from the harbor entrance.

Installation of the Waverider buoy and single pressure sensor is fairly straightforward, requiring only a small craft. The standard Datawell mooring has been employed successfully with few modifications. A tripod or jetted pipe is most often used for the single pressure sensor installation. Some innovation is needed when installing the array because of its size. When available, an amphibious vehicle can be effectively used to deploy the array and lay the cable from offshore across the surf zone and beach to the shore station. On two occasions when an amphibious vehicle was unavailable, an array was carried as a sling load beneath a US Army Reserve Chinook helicopter. The cable spool was carried inside its cargo area.

Figures 2 and 3 show the data collection sites currently being operated under the FWGP and provide information on gage type, percent data return, operational status, and gage ownership in programs other than this one. Operation of the system has been successful. Many of the stations that are not operational were lost or damaged during the severe storms in the early months of 1983 or as a possible result of that year's persistent "El Nino" current. Several arrays sustained cable damage as a result of beach protection or restoration efforts. An increase in buoy losses was experienced that appears attributable to the migration of commercially fished species as a result of "El Nino" and the expansion of the commercial fishing market to include species not previously considered marketable. All but one of the gages should be operational in 1984.

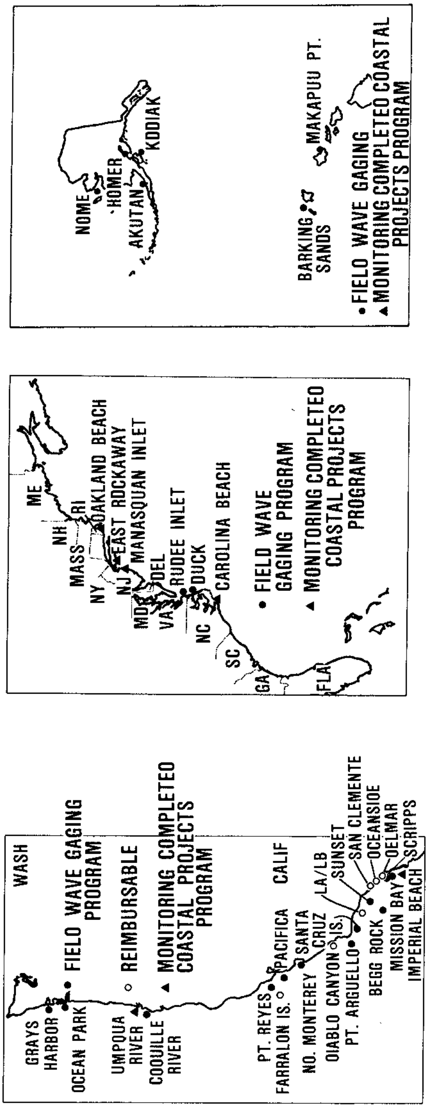


Figure 2. Data Collection Sites

DATA COLLECTION REPORT

MONTH OF: June 1984

| Program | Gage Location | Gage Type | Current Month | Year To Date | Comments |
|---|---|---|---|---|---|
| FWGP | Mission Bay, CA | Buoy | Hit by barge - to be replaced | | |
| | Mission Bay, CA | Array - Energy<br>- Direction | Cable damage - to be replaced | | |
| | Scripps, CA | Single pressure | 98.3% | 90.9% | |
| | Begg Rock, CA | Buoy | 95.8% | 83.4% | USN owned |
| | Santa Cruz ls., CA | Buoy | 85.4% | 85.9% | USN owned |
| | Sunset, CA | Array - Energy<br>- Direction | Cable damage - to be replaced | | |
| | Pt Arguello, CA | Buoy | To be replaced | | |
| | N. Monterey Bay, CA | Buoy | Lost to trawler - to be replaced | | |
| | Pacifica, CA | Array - Energy<br>- Direction | To be replaced | | |
| | Humboldt, CA | Buoy | To be replaced | | |
| | Coquille R., OR | Buoy | To be replaced | | |
| | Coquille R., OR | Array - Energy<br>- Direction | 98.3%<br>0.0% | 91.4%<br>0.0% | Cable damaged by vandals |
| | Ocean Park, WA | Array - Energy<br>- Direction | 94.2%<br>91.7% | 93.3%<br>89.7% | |
| | Grays Harbor, WA | Buoy | To be replaced | | |
| | Makapu'u Pt, HI | Buoy | 100.0% | 95.4% | |
| | Barking Sands, HI | Buoy | To be replaced | | USN owned |
| | Duck, NC | Array - Energy<br>- Direction | 96.7%<br>93.3% | 95.4%<br>91.8% | |
| | Rudee Inlet, VA | Array - Energy<br>- Direction | Abandoned | | |
| MCCP | Imperial Beach, CA | Array - Energy<br>- Direction | 99.2%<br>20.8% | 93.5%<br>63.2% | MCCP owned |
| | Umpqua R., OR | Buoy | 99.2% | 77.1% | Installed May 20, 1984 |
| CCSTWS | Del Mar, CA | Array - Energy<br>- Direction | 97.5%<br>95.8% | 93.4%<br>92.1% | CCSTWS owned |
| | San Clemente, CA | Array - Energy<br>- Direction | 90.0%<br>90.0% | 91.6%<br>89.9% | |
| SPL | Oceanside, CA | Array - Energy<br>- Direction | 97.5%<br>97.1% | 92.0%<br>91.2% | SPL owned |
| City of SF | Farallon is., CA | Buoy | 98.3% | 91.2% | City of SF owned |
| PG&E | Diablo Canyon, CA | Buoy | 90.8% | 85.4% | Adamo-Rupp Installation for PG&E |

Figure 3. System Status

Nearshore gages installed in support of specific projects supplement the data collected under the FWGP. On the Pacific coast, nine project-supported gages are operated through the FWGP network and the data reported by Scripps in the program's reports. The program, therefore, provides an existing system through which project-specific data can be collected, analyzed, and reported, taking advantage of the FWGP computers at Scripps. The system provides the considerable capacity and flexibility needed for coastal data collection and can accommodate any continuously reporting instrument. Tide, surge, current, wind, and wave data are being or have been collected on the system.

Related Data Collection Programs

Alaska's coastal data needs are unique. The State has approximately 54,500 km (33,900 miles) of coastline with a climate varying from temperate to arctic. With communities heavily dependent on the sea scattered along the entire coast, the State needed a planned approach to its coastal data collection efforts. In 1982, a cooperative agreement was signed between the State of Alaska and the Corps of Engineers to collect coastal wind and wave data. The goals stated in that agreement were, briefly, to collect, analyze, report, and archive coastal data collected by either party; to develop a plan for the collection of coastal data; and to develop instruments, telemetry systems, and analysis procedures suited to the needs and environment of Alaska (1).

Figure 2 includes the sites currently instrumented in Alaska. The Alaska Coastal Data Collection Program (ACDCP) is supported by funds from the State Department of Transportation and Public Facilities (DOT/PF), the Corps of Engineers, Alaska District, and the FWGP. Short-term (two to three years) data collection is planned to begin at 17 sites over the next 5 years.

Two types of stations have been developed: one for deep water and the other for nearshore measurements; both include a remote anemometer. For the deepwater sites, Waverider buoys are used. Nome is the only station currently in shallow-water operation. There the instrumentation consists of a pressure gage and current meter to provide directional wave data. Data from both station types are telemetered to a shore station and recorded on magnetic tape. Because data transmission over telephone lines is not reliable in Alaska, a meteor burst transmitter is used to send real-time data to the Corps office in Anchorage. The system uses meteor trails in the upper atmosphere as the medium from which the data are reflected. Meteor burst allows the data to be transmitted over great distances without the use of satellites or telephone lines and provides an inexpensive system check.

US Army Engineer District, Alaska, publishes data reports periodically as data are processed. To date, two reports have been produced for the station at Kodiak. The data reports provide the average wind speed and direction, maximum wind speed, and standard deviation of the wind speed and direction for each data collection. Both wind and wave data are reported every three hours. Wave data reported include the significant wave height, total energy in the spectrum, and the percent of the energy in frequency bands of 0.02148 Hz width. As more stations become operational, the data reports will be published more frequently.

Another cooperative effort that receives some support from the FWGP involves a contract with the University of Florida to collect, analyze, and report wave data from the Florida coast. The gaging effort is funded by the Corps of Engineers through the Hurricane Surge Prototype Data Collection Work Unit and the FWGP, by the State of Florida, and by the US Nuclear Regulatory Commission. Eight sites in Florida are operated by the University as the Florida Coastal Data Network (FCDN) using bottom-mounted single pressure transducers. Recently, three P-U-V in situ recording meters were added to provide directional wave data.

The FCDN provides real-time data in support of the hurricane surge work unit. Data reports are produced monthly by the University of Florida for each of the sites operated under the contract. Both tables and plots are used to report the wave data, which are collected every 6 hours. Plots of maximum period and significant wave height versus time are included in the reports. The tables provide significant wave height, total energy in the spectra, and the percent energy in various period bands from 4 to 22+ seconds for each data collection (4).

## Data Collection, Analysis, and Reporting

The data collection system developed by Scripps and used by the FWGP is based on burst rather than continuous sampling. While sampling frequency is field selectable, depending on the data to be collected, it is typically set at 1 hertz for ocean waves measured for the FWGP. The standard sample size is 1024 points, yielding 17 minutes of data. Normally each instrument is interrogated once every 6 hours, although certain critical stations are called every 3 hours and the data transmitted to the National Weather Service.

A block diagram of the collection and analysis system is shown in Figure 4. Signals from as many as eight input channels are received by a weatherproof shore station near the sensors. This station, which contains the data conversion and storage capability, control and power systems, and telephone interfaces, is modular. All electronics are on plug-in cards to facilitate the replacement of faulty components and minimize a station's down-time. Current incoming data are maintained in a digital buffer memory which expels the oldest words on a first-in first-out basis, ensuring that the most recent data set is in the buffer.

A control computer (a NOVA 1200 located at Scripps) initiates a telephone call to the shore station using an autodialer and normal telephone lines. The shore station, when called, locks the most current words in memory and transmits the data in a special 1200 Baud synchronous format to a digital data receiver at Scripps. Once all the data are transmitted, typically in slightly over one minute for four data channels, the shore station disconnects itself from the telephone line. Header information is then added, and the record is written on magnetic tape. During data transmission from the shore station, signal quality checks are performed. Failure of a quality check results in a second

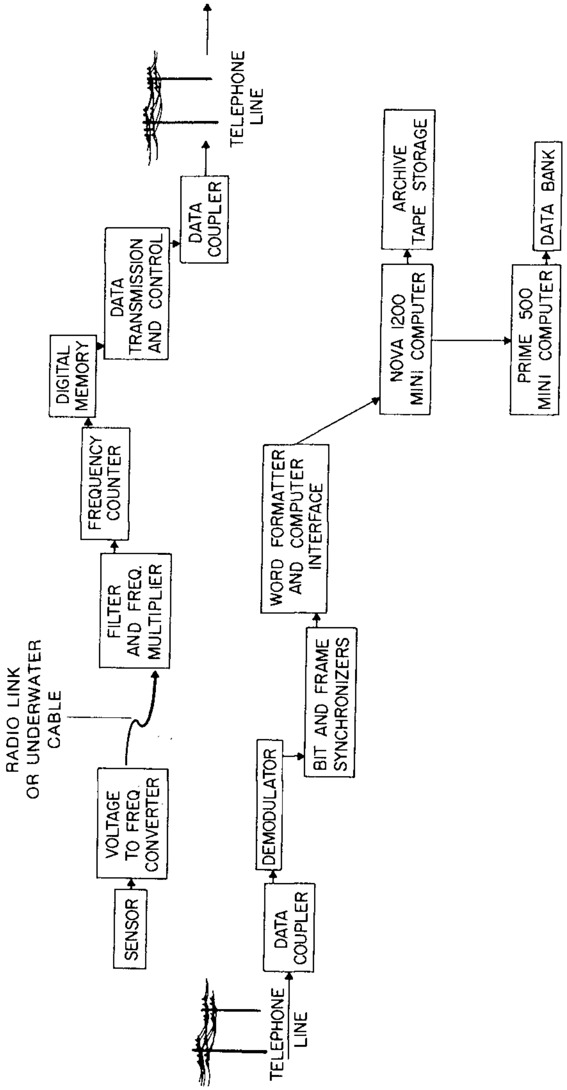


Figure 4. Data Collection and Analysis System

From Seymour, et.al., in press

call causing the immediate retransmission of the original data from the shore station. This protocol is important in the correction of transmission errors (9).

After the quality check, the raw data are put onto disks in a large mini-computer (a Prime 500 which serves as the central processing computer) for quasi-real-time analysis. The Prime and the NOVA are connected with a bidirectional serial link, allowing data and command flow in both directions. The NOVA can be remotely accessed through the Prime to make functions such as test calls, status checks, and raw statistics available from remote terminals.

Data analysis is composed of three phases. The first phase involves the receipt of the raw data from the NOVA and extensive data verification and editing in preparation for the second phase. An analysis phase performs the Fast Fourier Transform operations on the edited time series. The final phase operates on the analyzed data to produce the end products, monthly and annual reports.

In the first phase, an editing routine provides an automated data assurance scheme operating on the massive daily influx of data after their acceptance by the central computer. The editor is programmed to objectively recognize certain anomalies, to correct the more obvious ones, and to reject the others as bad data. It also compiles daily summaries and monthly statistics on the frequency and type of errors. The types of errors are spikes (the most frequent cause of data rejection), flat spots, mean shift exceedence, absence of zero crossings, and maximum and minimum wave height exceedence. Additionally, the editor filters the time series to remove tidal components and intercompares the individual sensor variances to evaluate acceptability of data for determining wave direction from the arrays.

Edited data for both gravity and infragravity waves are then Fourier transformed and the energy spectra calculated. Spectral values are grouped into period bins and summed to yield the variance. From the variance, the significant wave height is determined and the period band containing the maximum energy in the spectrum is identified. The data analysis routine also determines the percent of energy in each of nine period bands ranging from 4 to 22+ seconds.

Higgens, Seymour, and Pawka (3) describe the analytical method for extracting wave directionality from the sea surface slope components measured by the array. The method developed by Longuet-Higgins, Cartwright, and Smith (5) for use with a pitch-and-roll buoy is adapted for use with the array. An estimate of the longshore component of radiation stress, $S_{xy}$, can be extracted when surface elevation and components of sea surface slope are known at a point. The components of the slope are determined from differences between a pair of sensors. While only three sensors are required for this analysis, four are used for redundancy.

> Routine analyses of wave direction involves calculation of a spectrum of the longshore component of shoreward-directed radiation stress, which, with the energy spectrum, allows the estimation of an apparent arrival direction for each band of

periods. Summing the radiation stress components over all frequencies yields total $S_{xy}$. From this, and the total energy, a significant angle of arrival for all the wave energy can be estimated (9).

In addition to the products previously discussed, the distribution of $S_{xy}$ in the period bands is reported.

The significant data collected under the FWGP are available to users in three forms: direct access via remote terminals, data archives at Scripps and the US Army Engineer Waterways Experiment Station (WES), and monthly and annual reports. Data processed since the program's inception are directly available to any user with a computer terminal capable of remote telephone access of the Prime at Scripps. A user-friendly program has been developed to call up tabular and plotted data, including data for single or multiple stations on a single day, a single station on multiple days, or overplotted spectra to allow visualization of a storm's passage. Edited raw data are archived on tape at both Scripps and WES and can be made available to users under certain conditions.

Monthly and annual reports produced by Scripps provide the widest dissemination of wave data collected within the FWGP. After the first month of operation of the original program in 1975, a report was issued showing spectra and other wave parameters for Imperial Beach, CA. Every month since, analyzed data have been provided through these reports to a large group of public and private users. These data are summarized in an annual report which includes descriptive statistics on wave height and period as well as longshore sediment transport.

## Future Effort

A nationwide network of index sites, including the Great Lakes, is the goal of the FWGP, and that goal will be pursued during the next few years. Growth of the program will be gradual, but the importance of obtaining long-term wave data should ensure that expansion.

## Acknowledgement

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