INNOVATIVE TOOLS FOR MANAGEMENT:
REAL-TIME OCEANOGRAPHIC MEASUREMENTS AND CIRCULATION MODELING

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ABSTRACT

Special applications of real-time water level and current data and results of circulation models promise substantial benefits, including economic gains and safety of life, property, and the environment. Potential economic benefits for maritime commerce alone are estimated conservatively at about \$35.4 million annually for 22 United States ports, after deducting system operating costs. The corresponding benefits include reduced deadtime waiting to enter or leave port, more efficient use of lightering and of tugs used for docking and undocking, and full use of the ship channel depths.

1. INTRODUCTION

Real-time measurement of currents, water levels and winds, and numerical circulation models are proving to be innovative and profitable tools for a growing number of operational and management applications. They are particularly useful for piloting and docking large ships safely and efficiently, conducting diving or engineering operations during which current speeds or water levels are critical, managing the clean up of oil and hazardous materials spills, and addressing a wide variety of environmental management issues. Successful applications of real-time oceanographic measurements and numerical circulation models are translatable into dollars and safety of life, property, and the environment. These relatively new tools were made possible by three major advances that occurred during the past decade:

- enormous improvements in the capacity and speed of computers;
- improvements in circulation modeling and numerical methods; and
- important advances in commercially available, reliable, real-time measurement technology.

2. MODELS DRIVEN WITH REAL-TIME MEASUREMENTS

Three years ago, the National Ocean Service (NOS) demonstrated the viability of combining real-time measurements with a numerical circulation model for the Delaware River and Bay. Real-time water levels measured at the open ocean boundary, historical river flow data, and wind forecasts from the National Weather Service's Limited Finemesh Model were used to drive the model. Future enhancements would include using real-time river flow and wind data. The two-dimensional, vertically-integrated form of the Mellor-Blumberg model (Blumberg and Mellor, 1980) was applied to the Delaware Bay, from the entrance to Artificial Island, and the one-dimensional form was applied to the Delaware River, from Artificial Island to Trenton. Thirty-six-hour circulation and water level forecasts were produced twice each day by the model. The forecasts were compared to real-time water level data at three locations within the modeled area, and to real-time currents and winds at Brandywine Shoals situated at mid-Bay.

The integration of the real-time measurement system with the circulation model to provide operational forecasts was scientifically and technically successful. However, the impact of the project on the National Meteorological Center computer facility and the costs and personnel requirements to operate and maintain the real-time measurement system and produce twice-daily forecasts outweighed the advantages. Economic versus environmental pressures continue to increase, and it may be a matter of time when operational models using real-time data and weather forecasts will become cost-effective for certain key estuaries.

3. NOAA TIDAL CIRCULATION AND
WATER LEVEL ATLASES

NOS is using model-generated simulations of circulation and water levels to develop a new product line - estuarine tidal circulation and water level forecast atlases. The atlases will supplement NOAA's traditional

tide and tidal current prediction tables, and they will replace the traditional tidal current charts. The new atlas is described in a paper published in these proceedings entitled "The Circulation and Water Level Forecast Atlas: A New Product in Development at NOS" (Parker and Patchen, 1987). The first of these atlases is for the Delaware River and Bay; it is at the printers, and will be distributed during December.

The major advantage of the new atlases compared to the traditional tables and tidal current charts is that predictions can be presented graphically throughout an estuary. Tide predictions in the traditional tables are limited to shore sites where data were collected, but the model-generated atlases will show tidal heights, coranges, and cophases over the entire estuary. Current predictions in the traditional tables and charts are given only at locations where data were collected, but the atlases will show current vectors and lines of cophase and cospeed throughout the estuary. This enables NOAA to provide essential data in ship channels where water level and current data could not be obtained with moored instruments.

NOS oceanographers are presently conducting applied research to determine how nontidal phenomena can be included in the forecast atlases. These include the effects of variable river flows, and winds and barometric pressure differences both on the adjacent continental shelf and directly over the estuary.

4. REAL-TIME OCEANOGRAPHIC MEASUREMENTS

Real-time measurements of currents, water levels, and winds are made by NOS both for quality assurance of its traditional prediction tables and to obtain new data for driving and validating numerical models.

Real-time water level observations and predictions at 16 NOS gage locations in 9 states, listed in Table 1, are available to the public through the PC-based TIDES ABC system. TIDES ABC software is menu-driven, interrogates stations on demand, computes predictions for any day through 1997, provides convenient graphic displays of observed versus predicted data or anomalies versus predicted data, and produces tabular data. NOS operates the National Tide and Water Level Observation Network, and the 16 gages accessible to TIDES ABC users are part of the network.

Table 1. Water Level Gages Accessible by TIDES ABC

Cape May NJ	Charleston SC
Philadelphia PA	Point San Luis CA
Lewes DE	San Francisco CA
Tolchester Beach MD	La Jolla CA
Annapolis MD	Crescent City CA
Windmill Point MD	Toke Point WA
Baltimore MD	Neah Bay WA
Chesapeake Bay	Boston MA
Bridge-Tunnel VA	

Nine other stations in New York, New Jersey, Oregon and Washington provide real-time water level data for navigation and dredging control, but these are not owned by NOS and their data are not available to the public through TIDES ABC.

There is no analogous current measurement network. Real-time current measurements made for the NOS National Circulation Program are associated with special projects that may last from a month to several years. The 1-month deployments are associated with quality assurance of the traditional current prediction tables, and the longer deployments are to revise the existing predictions and generate new ones, and to validate circulation models. NOS makes data available to other users, and it enters into cooperative partnerships with local interests to conduct joint projects.

An experimental real-time current system was installed by NOS in Government Cut, the entrance to Miami Harbor, during December 1984 (Appell *et al*, 1985), and it remained in operation until August 1985. The system was used and evaluated by the Biscayne Bay Pilots Association. The pilots found this system useful, and the Port of Miami is planning to install its own system, including real-time winds and water levels (Lunetta, 1985; Bulloch, 1985).

NOS installed a remote acoustic real-time current system at the entrance to Charleston Harbor during April of this year, and it is still in operation. The system is described in papers by Hayes *et al* and G. F. Appell *et al* also presented at this conference. A novel, user-friendly software package in development by NOS and named CURRENTS ABC is being used and evaluated by the Charleston Harbor Pilots Association on an experimental basis. CURRENTS ABC, similar to TIDES ABC, allows immediate access to data from the remote acoustic Doppler system at the entrance to the Harbor. The real-time observations together with the predicted currents are displayed very effectively in a variety of graphical presentations or tabular forms. These data, along with real-time water levels at the Custom House Wharf available with TIDES ABC, provide invaluable information for the pilots. The South

Carolina Sea Grant Consortium is interacting with various potential users of a more comprehensive real-time system to determine how such a system could be procured, installed, and maintained locally.

5. BENEFIT ANALYSIS

Some cost savings from more efficient ship and dredging operations are already being realized as a result of the new tools, i.e., real-time measurements and data products derived from numerical circulation and water level models. Projected economic benefits of real-time systems for some areas appear to be sufficient to amortize the systems during the first year. The benefits include:

- reduced deadtime waiting to enter or leave port;
- more efficient use of lightering;
- more efficient use of tugs for docking and undocking;
- full use of channel depths (maximum safe draft);
- safer transits, docking and undocking (minimized costs due to property and environmental damage); and
- improved means to control treatment plant discharges.

There are additional benefits in estuaries where military ports and bases are situated, but defense-related benefits are not covered in this paper.

Benefits From Improved Depth Information

A "first-order" estimate of benefits related to vessel draft and controlling channel depth points to ports where substantial savings are possible. This estimate is based upon the number of inbound and outbound transits of merchant vessels in which the vessel drafts (D) were equal to or greater than the controlling depth of the channel (Z) at lower low water. These transits require "riding the tide" to gain sufficient safe depth below the keel. The data for this analysis were derived from the Corps of Engineers' "Waterborne Commerce of the United States - Calendar Year 1984" (the most recent edition), and NOAA's Coast Pilot. Hypotheses about the extent to which these transits could be affected by improved depth information are based on personal communications with state pilots (Zapf, 1983; Pedrajo, 1985; Ives, 1986; Delano, 1986; and Smith, 1987).

There were 59 ports in the continental United States and Alaska where ship drafts exceeded the controlling channel depths (D>Z) during 1984. The vessels include passenger and cargo ships, tankers, tugs and tows, and barges. The greatest number of transits with D>Z occurred in the Houston Ship Channel where 778 such transits occurred. Tampa was second with 521 transits, and Miami Harbor

was third with 492 transits. In addition to these top three ports, there were 7 ports where over 200 transits occurred with D>Z, and 19 ports where more than 100 similar transits occurred. The distribution of transits by vessel types for all 59 ports is shown in Table 2.

Table 2. Summary of ship transits where draft exceeds controlling depth (D>Z).

	<u>Inbound</u>	<u>Outbound</u>	<u>Total</u>
Passenger/ Dry Cargo:	1191	2416	3611
Tanker:	2175	724	2899
Tug and Tow:	138	144	282
Barge:	133	93	226
<u>Total</u>	3637	3377	7014

For a "first-order" estimate, only those ports where more than 100 transits occurred are included; they are listed in Table 3.

Table 3. Ports where 100 or more D>Z transits occurred during 1984.

	<u>Outbound</u>	<u>Total</u>
Houston Ship Channel	408	778
Tampa	416	521
Miami Harbor	230	492
Port of New Orleans	287	373
Penobscot River	101	353
Inner Harbor		
Navigation Channel	169	327
Jacksonville Harbor	98	233
Seattle	117	211
Freeport Harbor	14	208
Boston Harbor	30	206
Richmond Harbor	95	196
Grays Harbor	175	180
Tacoma Harbor	127	177
Long Beach Harbor	65	159
Baltimore Harbor	71	158
Oakland Harbor	79	157
Port Everglades	59	155
Savannah Harbor	69	134
Norfolk Harbor	132	132
Philadelphia	6	113
Charleston Harbor	50	105
Baton Rouge	50	101

The 22 ports listed in Table 3 account for 5,469 transits, or about 78 percent of the total D>Z transits that occurred during 1984. Estimates by state pilots and other knowledgeable sources suggest that one in five transits could have benefitted by real-time water level data through reduced waiting time, more efficient lightering, more efficient tug use, increased load, or a combination of these factors. According to this estimate,

approximately 1,100 D>Z transits could have been affected.

Decreased waiting time averaging 3 hours per affected transit amounts to approximately \$4 million; this assumes an average operating cost of \$1,200 per hour which is conservative for the size of the vessels. About \$2 million in operating costs could be saved through more efficient lightering and tug use.

Estimates of increased fees made possible by greater loading and maximum use of the channel depths should be limited to outbound traffic alone. It is unlikely that operators will know far enough in advance that destination ports will have higher than usual water levels, so the data are not useful under those conditions. The total number of outbound trips listed in Table 3 is 2,848, of which about 580 could have benefitted from real-time depth data, particularly if the data were accompanied by a simple statistical predictor. Increased fees related to increased draft vary over a large range, depending on the displacement of the ship and the type of cargo. A rough estimate suggested by several sources (Delano, 1986; Ives, 1985) is \$3,000 per added inch of draft. An average 6-inch increase in draft is reasonable considering that 1-foot nontidal water level increases are observed frequently. Under these assumptions, increased fees would amount to about \$12 million.

Damage to vessels through groundings can be avoided in some circumstances with improved water level data. The costs of oil and hazardous material spills may also be affected.

The total economic benefit related to real-time water level data is estimated at \$18 million per year, based on the 1984 statistics. With improvements in international trade and U.S. exports, this amount would increase substantially.

Benefits From Improved Current Data

Currents with their vector characteristics are far more difficult to predict accurately than water levels with their scalar characteristics. Differences between observed and predicted currents can be vital to safe navigation, and can be used to advantage in many instances. The advantages of having access to real-time current data are not limited to D>Z transits alone.

The National Transportation Safety Board (1979) stated one advantage succinctly: ". . . with reduced speed comes a reduction of maneuverability and an increase in crosstrack variability . . . the navigability of a 350-meter-wide waterway with 100 percent accuracy of the information about the current

is better than the navigability of a 670-meter-wide waterway in which the accuracy of the current is 75 percent."

Approaches to harbors where horizontal current shears or occasional reversals of expected currents occur can be made more safely with real-time current data. An 800-foot container ship collided with the cargo pier at the Port of Anchorage during March 1985 (McFarland, 1985) causing a 30-foot gouge in the ship's bow and destruction of part of the freight terminal. There was in excess of \$12 million in damage to the ship and the facility. This was a current-related casualty, similar to one that happened earlier in the same port, during October 1983. There have been numerous aborted attempts to moor ships at the Port of Anchorage because the currents there can become extremely complex, often with two or more bands of water moving in opposite directions along the approach, and with current patterns changing rapidly in time. These aborted attempts cost not only in vessel operation time but also in port facilities, e.g. crane operators, longshoremen, and container truck drivers.

Ships approaching the Houston Ship Channel on a northbound track expect to encounter a prevailing westward longshore current, but the longshore current is reversed under certain conditions. When this happens, passing other ships becomes a hazardous maneuver, whether they are inbound or outbound.

Anomalous currents are responsible for damaging several Navy ships during docking maneuvers at the Charleston Naval Base on the Cooper River. At this facility, ships are moored broadside to the current to finger piers. Unannounced discharge of water from Lake Moultrie to the Cooper River is a major cause of anomalous currents. Real-time current data in the Cooper River can be used to select the appropriate number of tugs for docking safely and economically.

In some ports, ship operators direct pilots to enter only during ebb currents and to exit only during flood currents. These directives to "stem" the currents are sometimes combined with instructions to use a certain number of tug boats. The Port of Miami is an example. Biscayne Bay pilots guiding Exxon tankers are constrained to enter port only during the ebb phase, and to exit only during the flood phase, using at least two tugs (Pedrajo, 1985). If a strong and persistent wind blows from the west over Biscayne Bay, the ebb current in Government Cut (the entrance channel) may be prolonged, and the time of slack water delayed. This condition allows inbound tankers a larger than normal time window, while outbound vessels may be delayed. On occasion, tankers, passenger ships, and cargo ships are able to enter port

later than the traditional current prediction tables would indicate when the real-time currents are known. This saves approximately 6 hours of dead time. While it is difficult to estimate the potential benefits on a nationwide basis, information from state pilots (Pedrajo, 1985; Zapf, 1983) suggests that about 1,700 hours of dead time may be saved by the availability of real-time current data. This translates to about \$2 million.

These incidents are but a few examples of many situations in various ports where real-time current data could be beneficial to the safety of life, property, and the environment. Estimating the total economic benefit of real-time current data is more difficult than for real-time water level data. On a National basis and averaged over several years, collision and grounding avoidance alone may equal or exceed the \$18 million dollar annual real-time water level data benefit.

6. SUMMARY OF ECONOMIC BENEFITS

The estimates of economic benefits described above are summarized in Table 4.

Table 4. Economic Benefits

Increased cargo fees	\$12 million
Reduced use of tugs/lightering	2
Reduced deadtime	6
Collision/Grounding Avoidance	18
<u>Total</u>	\$38 million

System Costs Versus Economic Benefits

The cost of a real-time system for the measurement of currents, winds, and water levels (each at one location) with data acquisition and display equipment is estimated at \$175K, plus or minus \$50K. Average installation cost is estimated at \$65K, plus or minus \$25K. System maintenance would be about \$40K per year, plus or minus \$20K, depending on biofouling rates, existing facilities, vandalism, and weather. About one-half of the ports listed in Table 3 would require measurements in two places. This would increase the procurement cost to about \$325K, the installation cost to \$100K, and the maintenance cost to \$70K per year. There is no history to estimate the expected life of the instruments, but a 5-year life is conservative based on our experience so far. The total life-cycle cost of the most basic type of system is \$440K, or about \$90K per year. The life-cycle cost of the multiple-sensor system is \$745K, or about \$150K per year.

If 11 basic systems and 11 multiple-sensor systems were installed in the 22 U.S. ports and harbors listed in Table 3, the total annual cost would be about \$2.6 million based on the estimates above. Compared to the National benefits estimated at \$38 million, the cost/benefit ratio would be 1:14 and the net annual benefit would be \$35.4 million.

This figure does not include benefits of more effective oil and hazardous material spill cleanup, better information for search and rescue in expansive estuaries, and long time series for analysis of dredging, shoaling, and environmental events. The analysis does not examine possible underwriters' premium reductions that may occur when statistics are adequate to show a direct link between real-time data and maritime casualty reductions.

Some ports would realize greater benefits than others and, with new dredging projects, the need for real-time water level data may diminish, but the approximations above suggests that real-time data can result in substantial economic benefits.

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