World-wide sand bypassing systems: data report

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Preface

This report has been prepared by Mr Paul Boswood, Coastal Services Branch, Environmental and Technical Services, Environmental Protection Agency, and Mr Russell Murray, formerly Project Director, Tweed River Entrance Sand Bypassing Project.

This report was prepared in 1996/97 as background information for the assessment of bypassing systems for the Tweed River Entrance Sand Bypassing Project. The information contained within this report has been obtained from a number of sources. The authors wish to thank all those who have provided assistance. In particular, the advice and feedback from project personnel within the Queensland Environmental Protection Agency, NSW Department of Land and Water Conservation, and Brown and Root as well as Queensland Transport, was greatly appreciated.

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i. List of symbols

AC = asbestos cement.
CD = Chart Datum.
cyl. = cylinder.
D_{50} = median sediment particle size.
dia. = diameter.
dir = wave direction.
HDPE SDR-9 = high density polyethylene standard density rating.
H_{max} = maximum wave height.
Hrs Op = hours operation.
Hs = significant wave height.
Hs(10%) = significant wave height exceeded 10% of the time.
Hs(50%) = significant wave height exceeded 50% of the time.
Hs,o = deep water significant wave height.
ID = inside diameter.
LWD = low water datum.
MDPE = medium density polyethylene.
MHHW = mean higher high water.
MLLW = mean lower low water.
MLW = mean low water.
MSL = mean sea level.
NW = north-west.
pa. = per annum.
PVC = polyvinyl chloride.
S = south.
SE = south-east.
std dev. = standard deviation.
SW = south-west.
T = wave period.
T_{ave} = average wave period.
T_p = spectral peak wave period.
typ. = typical or typically.
WNW = west of north-west.

ii. Dimensions and units

cy = cubic yard.
ft = feet.
gpm = gallons per minute.
hp = horse power.
hr = hour.
km = kilometre.
kV = kilovolt.
kW = kilowatt.
kWh = kilowatt hour.
lps = litres per second.
m = metre.
m^3 = cubic metre.
m^3 pa = cubic metres per annum.
m^3/yr = cubic metres per year.
mm = millimetre.
s = second.
yr = year.

1. Introduction

The Tweed River Entrance Sand Bypassing Project is a joint project undertaken by the State Governments of Queensland and New South Wales in conjunction with the Gold Coast City Council and Tweed Shire Council. The main aims are to establish and maintain a navigable entrance to the Tweed River and to enhance and maintain the amenity of the southern Gold Coast beaches.

The project involves two inter-related components, namely:

- initial dredging of the Tweed River bar and entrance area and nourishment of the southern Gold Coast beaches between Snapper Rocks and North Kirra (Stage 1).
- an artificial sand bypassing system, to operate in perpetuity (Stage 2).

To aid project delivery, world-wide experience operating various sand bypassing systems has been examined for their potential application to this project, and to expand knowledge on existing bypass technology and problems encountered.

This data report provides:

- a non-exhaustive reference list as of 1997;
- a short description of world-wide bypassing systems; and
- a set of data sheets providing a detailed brief description of selected bypassing systems.

It provides a reference source for the project team, consultants engaged for the project, potential contractors, regulating authorities, advisory bodies, the community and others with an interest in sand bypassing.

2. Terminology

This report summarises sand bypassing works undertaken around the world, with international references to these systems. Terminology used to describe key coastal works components will vary according to geographic location. This report uses the following terms for some of these key components:

Training wall: coastal structure aligned along the inlet sides and extending seawards to stabilise an inlet entrance and maintain a channel. Sometimes referred to as a jetty or breakwater.

Trestle: a structure extending seawards from the shore used for recreational rather than protective measures. Sometimes referred to as a jetty, pier, or wharf.

Breakwater: a coastal structure used to protect open coast regions from waves. Extensively used in harbours or mariners.

Weir Training Wall: a training wall with a depressed section of the wall usually near the beach to allow movement of sand into a controlled section of the channel. Usually associated with a sand trap to allow dredging in sheltered conditions.

Revetment: A protective layer usually of rock or concrete placed over a bank, scarp or in front of foreshore development to protect it from wave attack and currents.

3. Sand bypassing: general description

Natural sand bypassing is the process where the longshore sand transport (littoral drift) along an open coast travels across inlets in the direction of the net sediment transport. For inlets where the tidal prism of the inlet is small compared to the transport rate along the coast, a bar will form across the entrance of the inlet to convey sand to the other side. Such bars can be hazardous to navigation. Breakwaters or training walls may be erected along the entrance banks and seawards to stabilise movement of the inlet, to produce new inlets or harbours, and to improve navigation. While the result may be an improved entrance channel in the short term, the training walls trap the littoral drift such that the updrift beach accumulates against the training wall, whilst the downdrift beach erodes due to a lack of sand supply. In the long term, this process may continue until the sand can once again naturally bypasses around the entrance, creating another entrance bar.

To maintain a navigable entrance and neighbouring beach amenity, sand bypassing systems have been created to artificially bypass the littoral drift. A number of different systems have been developed and employed around the world. Most systems fall under one or a combination of the following generic types:
1. water based mobile systems including maintenance dredging either of the channel or sand trap;
2. land based mobile systems; and
3. fixed systems such as a trestle- or breakwater-mounted.

4. World-wide sand bypassing systems

A reference list has been prepared from a wide number of sources of information and is presented in section 8 below. Appendix A lists the world-wide sand bypassing systems found from a non-exhaustive search of the cited references. The locality of these systems are shown in figure A1.

No list of sand bypassing systems (including this one) can be regarded as fully complete because different definitions of bypassing are used in different jurisdictions and by different investigators. The list covers major systems in operation, other systems trialed or operated for a limited time, and some systems in development phase as of 1997.

5. Selected sand bypassing systems

Based on this list, the available references, and the knowledge of project staff, a selection of sand bypassing systems was chosen for a more detailed summary to cover a range of various types of systems in operation. The list of selected bypassing systems considered for a more detailed summary is given in table 1.

Table 1. List of selected bypassing systems.

Plant location	Country	Type of bypass system
Nerang River Entrance, Queensland	Australia	Trestle and jet pump system (fixed).
Boca Raton, Florida	USA	Weir training wall and trap with conventional dredging.
Channel Islands Harbour, California	USA	Detached breakwater and sand trap with biannual dredging and pumping down coast of Port Hueneme.
Dawesville, Western Australia	Australia	Crawler excavator (mobile) and crawler mounted pump system.
Indian River Inlet, Delaware	USA	Jet pump and crane (mobile system).
Oceanside Harbour, California	USA	Jet pumps and fluidisers (experimental fixed system).
South Lake Worth Inlet, Palm Beach County, Florida	USA	Fixed hydraulic suction dredge with a rotating boom (fixed).

A data sheet on each of these systems is given in appendices B to H. These data sheets provide a systematic description of key environmental and system parameters, a site description, and a specific reference list with some additional references not given in the bibliography. The measuring units provided in these appendices depends on the source of information and varies between metric and imperial. A description of unit abbreviations is provided in section 2.

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Appendix A

List of sand bypassing systems (as of 1997).

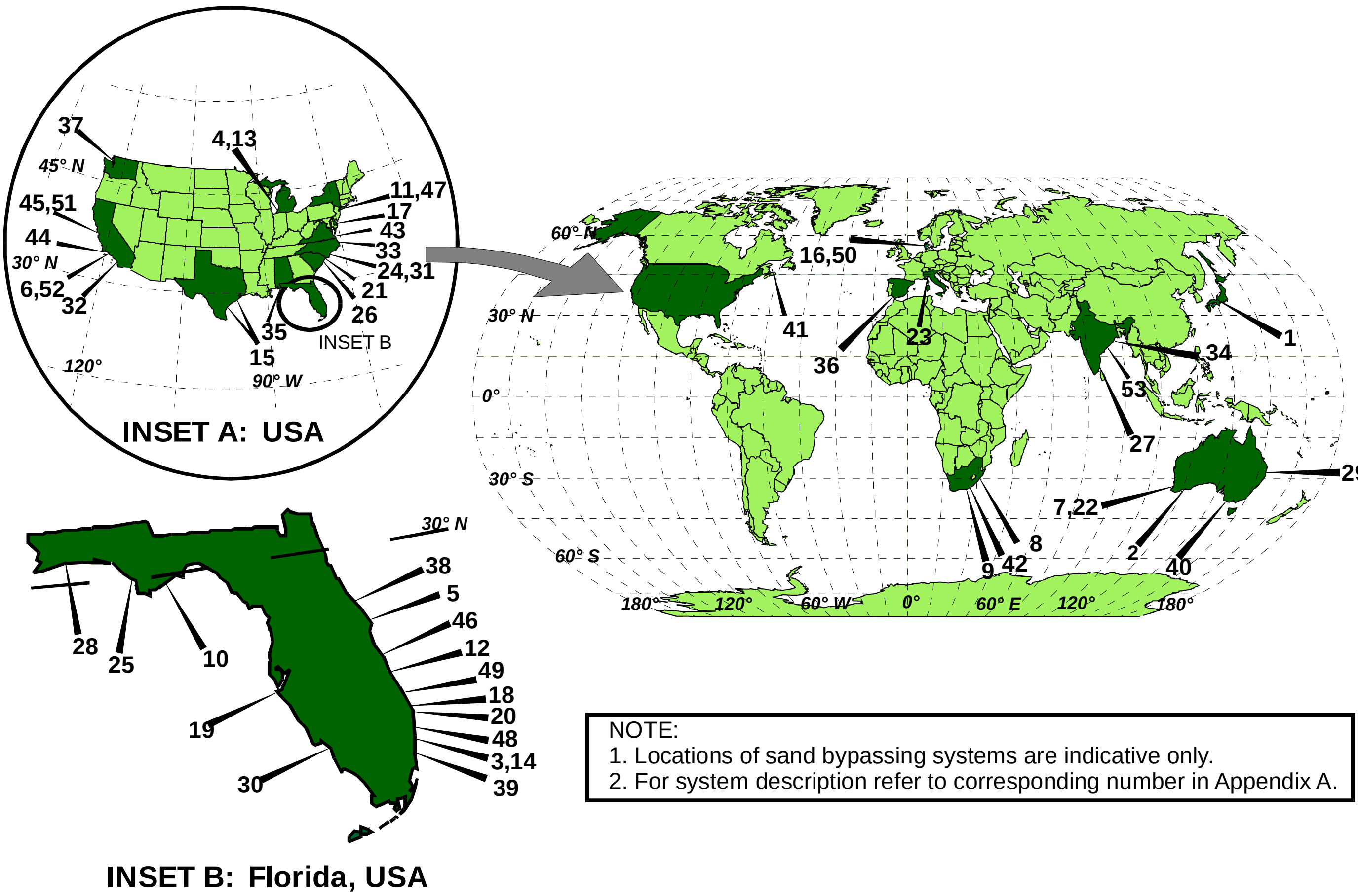
	Plant location	Country	Type of bypassing system [and reference]
1.	Amanohashidate coast	Japan	Investigation and trial only [54,258].
2.	Bandy Creek Harbour, Esperance, Western Australia	Australia	Natural bypassing around entrance with offshore breakwater to prevent sediment returning (constructed 1989) [24].
3.	Boca Raton, Florida	USA	Weir training wall and trap with conventional dredging [71,81].
4.	Bridgman, Michigan (Lake Michigan)	USA	Small quantities by hydraulic bypassing from accretion fillet with remainder of nourishment from mined sand from dunes (1971-1973) [120].
5.	Canaveral Harbour, Florida	USA	Conventional dredging from nearshore borrow area (recommended plan as of 1995) [108].
6.	Channel Islands Harbour, California	USA	Detached breakwater and sand trap with biannual dredging and pumping down coast of Port Hueneme [106,211,226].
7.	Dawesville, Western Australia	Australia	Crawler excavator (mobile) and crawler mounted pump system [22,50,111].
8.	Durban	South Africa	Maintenance dredging of entrance and trap updrift of breakwater (installed 1982). Considering fixed system of jet pumps as of 1996 [10,129,191].
9.	East London Port	South Africa	Maintenance dredging of trap [129].
10.	East Pass, Florida	USA	Weir training wall and trap with conventional dredging (1969-1985) [207].
11.	Fire Island, New York	USA	Maintenance dredging of bay shoals [41].
12.	Ft. Pierce, Florida	USA	Maintenance dredging of bay shoals [41].
13.	Great Lakes	USA	Mobile system consisting 200 mm jet pump with cutting assists, flotation buoy, and two propulsion jets connected by flexible hose to two land-based trailers supporting pumping and control equipment to travel between harbours (constructed in 1978) [189].
14.	Hillsboro Inlet, Florida	USA	Weir training wall and trap with 36 cm floating hydraulic dredge (mobile) [81,109].
15.	Houston, Corpus Christie, Texas	USA	Dredging of bay and ocean shoals with disposal offshore [41].
16.	Hvide Sande	Denmark	Maintenance dredging of entrance, as well as nourishment from offshore borrow site. Booster station in entrance for pumping during summer [115].

	Plant location	Country	Type of bypassing system [and reference]
17.	Indian River Inlet, Delaware	USA	Single jet pump and crane (mobile system) [1,6,56,61,65,67,69,96,131,181,182,183,234,240].
18.	Jupiter Inlet, Florida	USA	Conventional dredging of trap (constructed 1966) in Inlet [81].
19.	Lake LaVista Channel, Anna Maria Island, Florida.	USA	Demonstration of sand fluidisation system in 1986 [72].
20.	Lake Worth Inlet, Florida	USA	Electrically driven moveable suction head suspended from a boom (1960-1990); and maintenance dredging of entrance [150,191,203,211,227,261].
21.	Little River Inlet, South Carolina	USA	Weir in both training walls for bypassing. Weirs covered, to be opened when required [174].
22.	Mandurah Inlet, Western Australia	Australia	Crawler excavator (mobile) and crawler mounted pump system [22,50,111].
23.	Marina di Carrara	Italy	A 250mm suction pipe dredge mounted and swivels on a fixed circular concrete trestle off the updrift side of the harbour breakwater (installed 1972) [188,191].
24.	Masonboro Inlet, North Carolina	USA	Weir training wall and trap with conventional dredging (commenced 1966) [141,201,211].
25.	Mexico Beach, Florida	USA	Two fixed jet pumps operating from crater (constructed 1976). Replaced by floating dredge in 1978 [167].
26.	Murrells Inlet, South Carolina	USA	Weir training wall and trap with conventional dredging (mobile) [12,172].
27.	Nagapattinam (Bay of Bengal)	India	Pump on trestle pier with shutters [41].
28.	Navarre Beach, Florida	USA	Considering moveable dredge plant as of 1989 [23].
29.	Nerang, Queensland (Gold Coast Seaway)	Australia	Ten jet pumps along a trestle (fixed) (commenced 1986) [58,59,60,137,140,173,175,176,180,191,206, 216,256,257].
30.	New Pass, Florida	USA	Maintenance dredging of ocean shoal [41].
31.	New River Inlet, North Carolina	USA	Sidecasting dredge with split hull barge for deposition within 2m depth (experiment, 1976) [199,200].
32.	Oceanside Harbour, California	USA	Jet pumps and fluidisers (experimental fixed system, 1989 to 1996) [11,14,18,21,80,152,153,166,226,228, 246].
33.	Oregon Inlet, North Carolina	USA	Cutter-suction pipeline dredge operating in openings in proposed entrance walls (in consideration, 1985) [53,116,117].

	Plant location	Country	Type of bypassing system [and reference]
34.	Paradip, Orissa (Bay of Bengal)	India	Moveable plant on trestle with additional maintenance dredging [41].
35.	Perdido Pass, Alabama	USA	Weir training wall and trap with conventional dredging (construction commenced in 1968) [207].
36.	Playa de Castilla beach (Huelva Spain)	Spain	Trailing suction hopper dredge dredging shoals trapped by updrift dike, and pumping via 2 km long steel submerged pipeline to downdrift beaches [86].
37.	Point Roberts Marina, Strait of Georgia (northern Puget Sound), Washington	USA/ Canada border	Small-scale land based equipment bypassing beach sand by truck (mobile) [132,133].
38.	Ponce de Leon Inlet, Florida	USA	Weir training wall and trap with conventional dredging [201].
39.	Port Everglades, Florida	USA	Nourishment from offshore borrow site, and maintenance dredging [41].
40.	Portland, Victoria	Australia	Sand shifter system operated from breakwater or from barge [129].
41.	Prince Edward Island	Canada	Trailer-mounted jet pump and telescoping hydraulic crane (mobile, commenced 1982) [191].
42.	Richards Bay	South Africa	Maintenance dredging of trap [129].
43.	Rudee Inlet, Virginia Beach, Virginia	USA	Weir training wall and trap with conventional dredging (1968-1972). Two jet pumps on flexible hose (semi-mobile) installed in 1972 at trap, supplemented by maintenance dredging [188].
44.	Santa Barbara, California	USA	Maintenance dredging of harbour [211,226,248].
45.	Santa Cruz, California	USA	Annual maintenance dredging of entrance channel (commenced 1965 with floating pipeline dredge) [126,188].
46.	Sebastian Inlet, Florida	USA	Maintenance dredging of channel sand trap with periodic transfer to downdrift beaches (commenced in 1989) [229].
47.	Shinnecock Inlet, New York	USA	Design/construct of inlet including bypass system in process as of 1992 [156].
48.	South Lake Worth inlet, Palm Beach County, Florida	USA	Fixed hydraulic suction dredge with a rotating boom (fixed) [8,51,158,191,260].
49.	St. Lucie, Florida	USA	Weir training wall and trap with conventional dredging (proposed as of 1987) [41].
50.	Torsminde	Denmark	Maintenance dredging of entrance, as well as nourishment from offshore borrow site [115].

	Plant location	Country	Type of bypassing system [and reference]
51.	Twin Lakes Harbour, Santa Cruz, California	USA	Fixed plant (commenced 1972) [41].
52.	Ventura, California	USA	Detached breakwater (constructed 1972) and sand trap with annual dredging (bypassing and some backpassing) [226].
53.	Visakhapatnam (Bay of Bengal)	India	Detached breakwater trap and transfer by pipeline across entrance to harbour [41,79,185].

Figure A1: *Locality of world-wide sand bypassing systems.*



Appendix B

Data sheet: Nerang River Sand Bypassing System, Queensland, Australia.

Location:	The Nerang River flows to the sea through a broad shallow tidal estuary called the Broadwater, meeting the Pacific Ocean between the southern end of South Stradbroke Island and the Southport Spit. The entrance is located at the northern end of the City of Gold Coast, south-east Queensland, Australia.
Problem:	The progressive movement of the entrance northwards at a rate of 20 - 40 m per year has involved accretion of the Southport Spit and erosion of the southern tip of South Stradbroke Island. Hazardous navigation through the changing entrance shoals, and the possible threat of breakthrough at the South Stradbroke Island township of Currigee in the future, lead the Queensland Government to train and stabilise the river mouth between September 1984 to May 1986. The construction included revetments and breakwaters, opening of a new entrance and closure of the old entrance, creation of Wavebreak Island and Broadwater channels, and installation of a fixed bypass system.
Wave climate:	Based on recorded wave data offshore from Southport in approx. 40 m depth for 1987 - 1994: modal Hs(50%) = ~1 m H_{max} = 9.98 m during Tropical Cyclone Roger The majority of the waves range in height of Hs = 0.25 - 3.0 m (99 %) with 65 % of the data occurring within Hs = 0.5 - 1.25 m. The wave period (spectral peak) ranges typically between 3 and 15 s (99 %) with 65 % of the data within Tp = 7 - 11 s. The wave climate is influenced by the predominant south-easterly swells with intense storms associated with low pressure systems and tropical cyclones approaching from the north.
Inlet characteristics:	Nerang River: catchment = 480 km^2; semidiurnal mean spring tide range = 1.3 m extending to a limit of 21 km upstream from the mouth.
Inlet usage:	Recreational boating, fishing, and commercial vessels (for recreational hire).
Sediment characteristics:	D_{50} = 0.27 mm for the intertidal sands on adjacent beaches (ranges from 0.2 to 0.3 mm along the profile).
Drift rate:	Net northerly transport = 500,000 m^3/yr (~654,000 cy/yr) (Beach Protection Authority, 1981). Gross transport = 655,000 m^3/yr (~857,000 cy/yr). Northerly transport = 575,000 m^3/yr (~752,000 cy/yr). Southerly transport = 80,000 m^3/yr (~105,000 cy/yr).
Beach erosion rate:	The bypass system was constructed in conjunction with the training of the entrance and so there was no erosion as a result of the entrance. Before training of the inlet, there was a progressive movement of the entrance northwards at a rate of 20 - 40 m per year.
Type of bypass:	Ten jet pumps along a trestle (fixed).

Bypass system components:

Clear water intake from Broadwater through a 4 ft (~1.2 m) dia. concrete pipe; low pressure pump station with two 150 kW (200 hp) turbines (total 780 lps, 10,300 gpm); 24 inch (600 mm) dia. AC pipeline 2,300 ft (~700 m) long to the control building; high pressure jet water supply pumps housed in control station consisting of two 560 kW (750 hp) Centrifugal pumps (total 770 lps, 10,200 gpm); 14 inch (450 mm) coal tar epoxy lined water supply pipeline; 6 inch (150 mm) feed pipelines to jet pumps; ten 3.5 inch (90 mm) Genflo sandbug jet pumps with rate of 135 cy/hr (~100 m^3/hr) spaced 30 m apart along a 490 m long trestle; an elevated 23 inch (600 mm) dia. slurry pipe flume (1,214 ft or approx. 370 m long), on a 2.5 % slope to gravity feed into a density adjusting slurry pit which is a conical 189 cy (145 m^3) hopper; discharge pump housed in control station consisting of a 710 kW (950 hp) Centrifugal pump (total 489 lps, 6,500 gpm).

The jet pumps are lowered up to 11 m below mean sea level and create a trap of length 270 m. The trestle consists of a timber deck supported on steel piles. The jet pumps run on rails attached to the steel support piles to allow for installation and removal for maintenance work.

The operations are controlled by an automatic programmable logic controller. A nuclear density meter and electromagnetic flow meter are installed in the discharge line for the control of the flow rate and slurry solids concentration by the automatic system, and for operation monitoring records.

The system is powered by an 11 kV underground cable.

Outlet type:

406 mm (16 inch) dia. polyurethane lined steel pipe discharging at approximately the high water level, approx. 400 m north of the northern breakwater. Three outlet locations were considered in the design of the system, the further most discharge point being approx. 1,710 ft (~520 m) north of the northern training wall. The discharge pipe passes through steel sleeve tubes in the rock training walls for protection, and passes beneath the channel with pile supports.

Bypass rate:

Design Parameters:
Average rate = 500,000 m^3/yr; peak annual rate = 750,000 m^3; nominal transport capacity = 300 m^3/hr; maximum 5 day transport = 100,000 m^3; maximum monthly transport = 200,000 m^3; maximum sand trap capacity = 40,000 m^3.

The system was designed for the operation of 4 to 7 jet pumps with nominal capacities of 335 to 580 m^3/hr and an operating performance of 3.15 kWh/m^3. Operational experience has indicated the use of 3 to 5 jet pumps to be more effective.

Degree of bypassing: (e.g. all, 50%, etc.)

Designed for 100 % bypassing, however an unknown quantity of sand bypasses the trestle. No dredging of the entrance channel has been required.

Costs: Construction of bypass system and ancillary works (Jan 1985 - June 1986): $8,134,000 (AUD).

Operating expenses since commencement of bypassing: (July to June)

ITEM	89/90	90/91	91/92	92/93	93/94
Electricity	183,400	152,100	167,600	140,200	241,000
Salaries and Wages	90,700	93,400	95,000	102,800	95,700
Repair and Maintenance	111,900	100,100	184,000	318,800	266,200
TOTAL ($)	386,000	345,600	446,600	516,800	602,900

ITEM	94/95	95/96	96/97
Electricity	221,847	154,421	163920
Salaries and Wages	104,054	119,573	112,204
Repair and Maintenance	360,544	397,438	459,165
TOTAL ($)	686,445	671,432	735,289

Funding: State Government.

Contract type: Contract to design and construct. Operations and maintenance conducted by owner. A contract was let for the management of the structure as a fishing platform by the general public. In 1992, a painting contract was let for the complete painting requirements for the offshore structure.

Owner: State Government, Queensland Department of Transport.

Operator: State Government, Queensland Department of Transport.

Supervisor of operations: State Government, Queensland Department of Transport, Marine Services Section.

Staffing: Total of 3 people: an operator, assistant operator, and labourer working a normal daytime shift.

Operating cycle: The system runs automatically overnight, and sometimes weekends, to take advantage of cheaper electricity rates. The operator selects the appropriate jet pumps (depending on sand supply in each crater and the presence of debris) and commences pumping in the afternoon to run through the night. The system automatically performs an initial warm up and flushing of the lines, before the valves to the jet pumps are opened and bypassing commences.

Environmental constraints: No known constraints. Bypassing takes place at night and the discharge point is on an undeveloped part of an island, therefore having no direct effect on beach users.

Environmental management issues: A monitoring programme is undertaken to examine the performance and impacts of the entire project. This includes undertaking hydrographic surveys, aerial photography, sand bypassing records, visual observation of beach and surf zone conditions, wave recording, and the recording of water levels in the Nerang River and the Broadwater.

Commencement date of bypassing: May, 1986.

Performance:
(include any leakage to inlet, formation of entrance bar, etc.)

Summary of Sand Bypassing Statistics (July to June)

ITEM	89/90	90/91	91/92	92/93	93/94
m^3 Pumped	378,756	440,287	376,841	286,974	569,013
kWhrs	2,077,111	2,101,010	1,859,789	1,608,946	2,434,098
kWhr/m^3	5.48	4.77	4.93	5.61	4.28
Hrs Op	1839	1568	1433	1210	1642
m^3/hr	206	281	263	237	347
\$/m^3	1.02	0.78	1.18	1.95	1.06

Summary of Sand Bypassing Statistics (Continued)

ITEM	94/95	95/96	96/97
m^3 Pumped	570,293	408,917	563,831
kWhrs	2,250,130	1,566,335	2,146,236
kWhr/m^3	3.95	3.83	3.81
Hrs Op	1518	1117	1539
m^3/hr	376	366	366
\$/m^3	1.20	1.64	1.30

For the financial years (July to June) up to 1989/90, the system had delivered 138,236 m^3 (85/86), 544,002 m^3 (86/87), 464,435 m^3 (87/88), and 392,821 m^3 (88/89). For the 1997/98 financial year the system pumped a total of 587,869 m^3. The system operates with 3 to 5 jet pumps achieving capacities in the range of 330 to 540 m^3/hr depending on factors such as weather, blockages, density of sand and slurry, and sand supply to the traps. As of September 1998, a bypassing rate of approx. 420 m^3/hr has been able to be maintained owing to continual improvements to the efficiency of the system.

The system was originally designed to create a long continuous sand trap of 270m length under the trestle. However, in practice, individual steep slope craters (typically 1:1 to 1:1.5) have formed around each jet pump.

There has been an unknown quantity of sand bypassing the trestle and building a bar formation, but no maintenance dredging of the channel between or seaward of the walls has been required. There has been some build-up of sand requiring dredging at the Broadwater end of the entrance.

There has been some significant scouring of the channel from strong ebb currents which has exposed the discharge pipe. The pipe has subsequently been supported by piles. The ebb tidal bar is forming further offshore then prior to the works but is not a problem for navigation. Some occasional growth of the sand spit around the southern training wall and into the entrance occurs and there is a progressive sand build-up in the nearshore areas to the north of the entrance.

The jet pumps are subject to clogging from debris especially during and after storm events. This has resulted in the plant not being operational during storms as originally envisaged. Key components of the jet pumps have undergone severe wear and have been through a series of improvements to reduce the problem. Difficulties are also encountered in retrieving the jet pumps for maintenance works owing to the limited working area for the crane.

Present plant status:
(as of 1996)

Successful. Still in operation.

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Figure B1*: Nerang River Entrance Sand Bypassing System, Locality plan (Munday, 1995).*

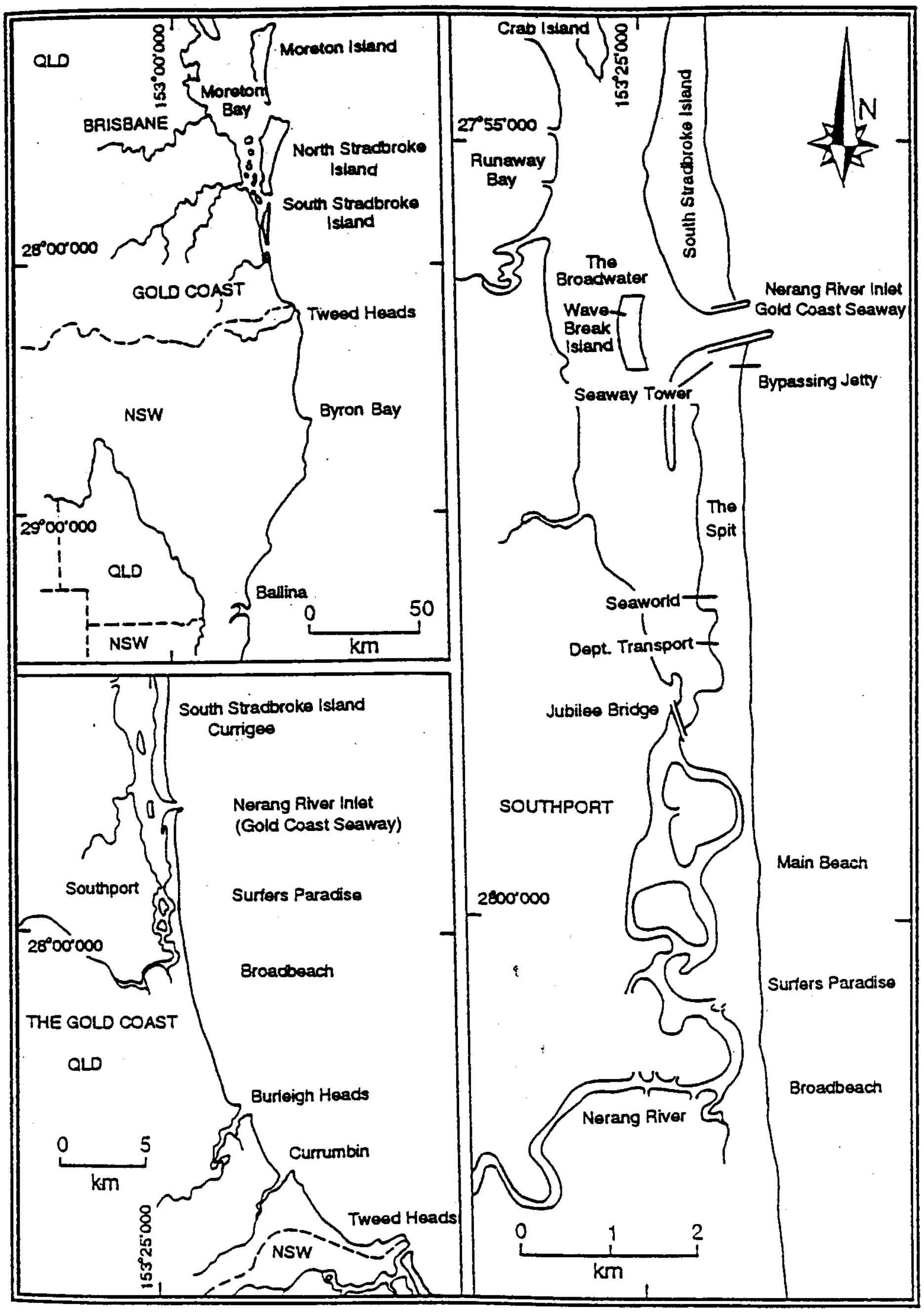


Figure B2: *Nerang River Entrance Sand Bypassing System, System layout (Witt and Hill, 1987).*

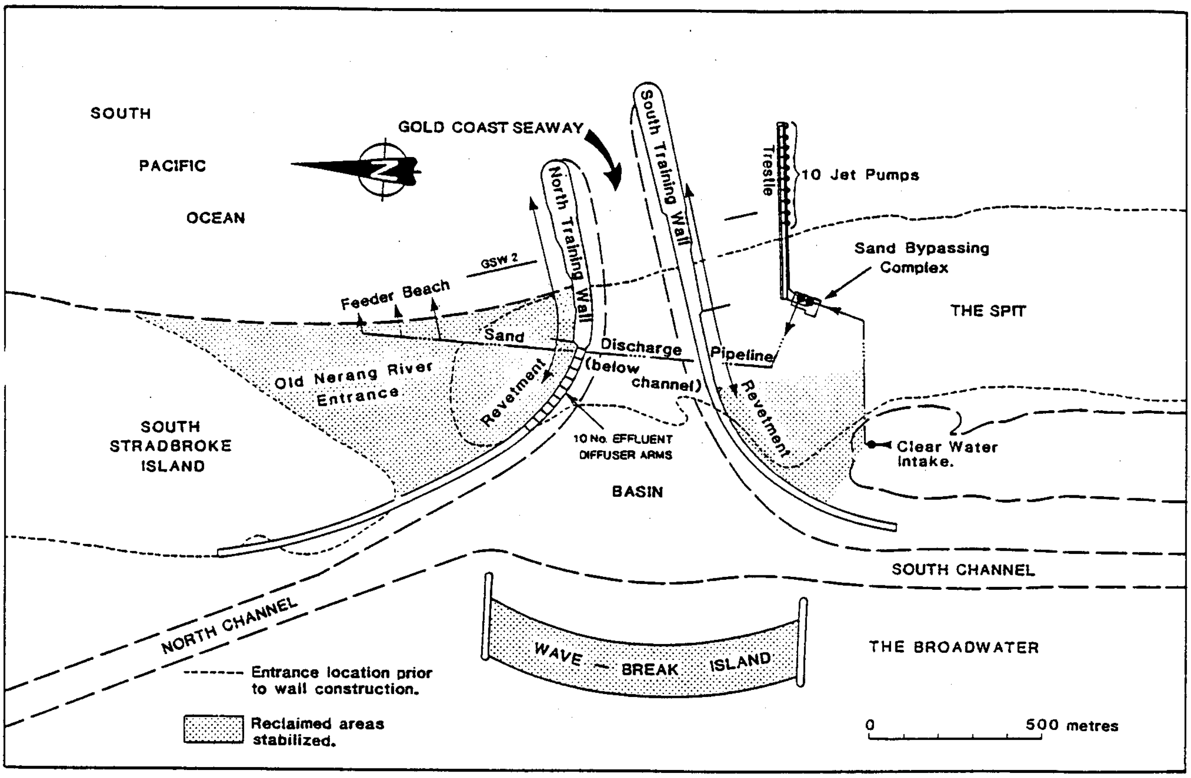
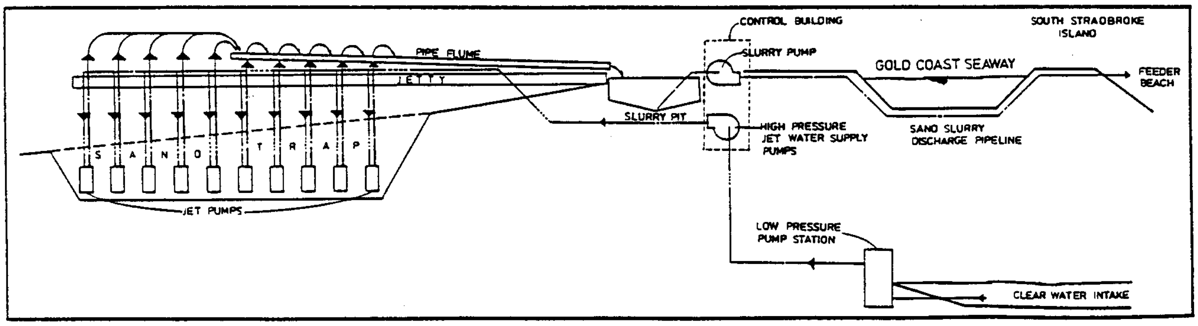


Figure B3: *Schematic of Nerang River Entrance Sand Bypassing System (Witt and Hill, 1987).*



Appendix C

Data sheet: Boca Raton Inlet Sand Bypassing System, Florida, U.S.A.

Location:	Boca Raton Inlet is a natural entrance connecting Lake Boca Raton to the Atlantic Ocean. The inlet is situated within the City of Boca Raton in the south-eastern region of Palm Beach County, Florida, USA, between South Lake Worth Inlet (23 km to the south) and Hillsboro Inlet (9 km to the north).
Problem:	Erosion of the southern beaches and the creation of an ebb shoal at the entrance becoming a hazard to navigation.
Wave climate:	No published information available for this site, however refer to the Data Sheet for South Lake Worth Inlet (Appendix H) which is 23 km to the north of this site, for some general idea of conditions.
Inlet characteristics:	Tide range = approx. 2.5 ft (~0.75 m).
Inlet usage:	Small craft from southern Palm Beach and northern Broward counties.
Sediment characteristics:	Not known.
Drift rate:	Net southerly drift = 93,000 m^3/yr (~122,000 cy/yr). Transport is to the north for nine months and to the south for three months of the year during winter.
Beach erosion rate:	1975 - 1979: following extension of the training walls, the beach immediately south of the inlet receded by 187 ft (~57 m). August 1985 - August 1995: following the 1985 nourishment which widened the southern beach (3,400 ft or 1036 m length) on average 75 ft (~23 m), the same beach had receded approx. 138 ft (~42 m) by August 1995. (Coastal Planning & Engineering, 1996)
Type of bypass:	Weir training wall and channel trap with conventional dredging (mobile).
Bypass system components:	1972: 335 hp, 8 inch (~200 mm) hydraulic pipeline dredge and small tugboat. 1975: northern training wall extended seawards 180 ft (~55 m). 1980: construction of a 65 ft (~20 m) long weir section in the northern training wall at 180 ft (~55 m) in from the seaward end of the wall; added a second engine to the tug; modifications to the dredge and spoil pipelines to facilitate the dredging of the inshore portions of the ebb tidal shoal. 1985: South Boca Raton Ebb Shoal Dredging/Feeder Beach Project placed 221,000 cy (~169,000 m^3) of sand from the ebb tidal shoal to a 3,400 ft (~1,036 m) length of beach south of the inlet. 1996: A second replenishment project is planned. The Boca Raton Inlet Ebb Tidal Shoal Sand Transfer Project provides for the dredging of another 252,000 cy (~193,000 m^3) of sand from the ebb tidal shoal to be placed on a 3,960 ft (~1.2 km) length of beach south of the inlet.
Outlet type:	Pipe discharge from dredge directly on to southern beach via approx. 200 mm PVC pipe.
Bypass rate:	Average bypass rate = 32,000 m^3/yr (~41,850 cy/yr).
Degree of bypassing: (e.g. all, 50%, etc.)	34 % artificial bypassing; 47 % natural (Dombrowski and Mehta, 1990).
Costs:	1972: purchase cost = $140,000 (US) for dredge and tugboat (Coastal Planning & Engineering, 1996).

Funding:	1972: City of Boca Raton All inlet/beach maintenance projects and monitoring activities are funded jointly by the Florida Department of Environmental Protection (75 %) and the City of Boca Raton (25 %) (Coastal Planning & Engineering, 1996).
Contract type:	Operated by the City of Boca Raton.
Owner:	Prior 1972: private ownership. After 1972: City of Boca Raton.
Operator:	City of Boca Raton.
Supervisor of operations:	Experienced dredge master, employed by the City of Boca Raton.
Staffing:	3 people.
Operating cycle:	The dredge is not certified for ocean operations and so cannot proceed past the end of the walls. Works within the entrance proceed with, and are governed by, the sand, wave, and current conditions. Operates during winter and intermittently during summer.
Environmental constraints:	Not known.
Environmental management issues:	Narrow inlet with heavy usage by recreational vessels. Heavy beach usage.
Commencement date of bypassing:	Dredge and tug commenced in 1972.
Performance: (include any leakage to inlet, formation of entrance bar, etc.)	The plant only bypasses 34 % of the southerly drift with 47 % naturally bypassing around the ebb tidal shoal. A further 18 % is retained by the northern training wall, and 1 % is deposited on the flood shoal. Strong currents exist within the narrow inlet and a bar offshore from the entrance requires dredging by other equipment occasionally. The amount of artificial bypassing did not stop erosion of the southern beach, while the natural bypassing had made navigation of the ebb shoal hazardous. The beach nourishment project of 1985 using sand from the ebb shoal, provided on average 30 % (28,000 m^3/yr based on a 6 year return period for nourishment works) of the annual littoral drift to the southern beach, resulting in a total of 111 % (103,000 m^3/yr) of the net southerly drift being bypassed both artificially and naturally. (Dombrowski and Mehta, 1993)
Present plant status: (as of 1996)	Still in operation.
References:	Coastal Planning & Engineering, Inc., 1996. *The Boca Raton Inlet Ebb Tidal Shoal Sand Transfer Project and Ongoing Interior Sand Transfer Program*, Brochure, 25th International Conference on Coastal Engineering, Orlando, Florida, USA. Dombrowski, M.R., Mehta, A.J., 1993. Inlets and Management Practices: Southeast Coast of Florida, *Journal Coastal Research*, Special Issue No. 18, Fort Lauderdale, Florida, pp29-57.

***Figure C1**: Boca Raton Inlet Sand Bypassing System, Locality plan (Coastal Planning and Engineering, 1996)*

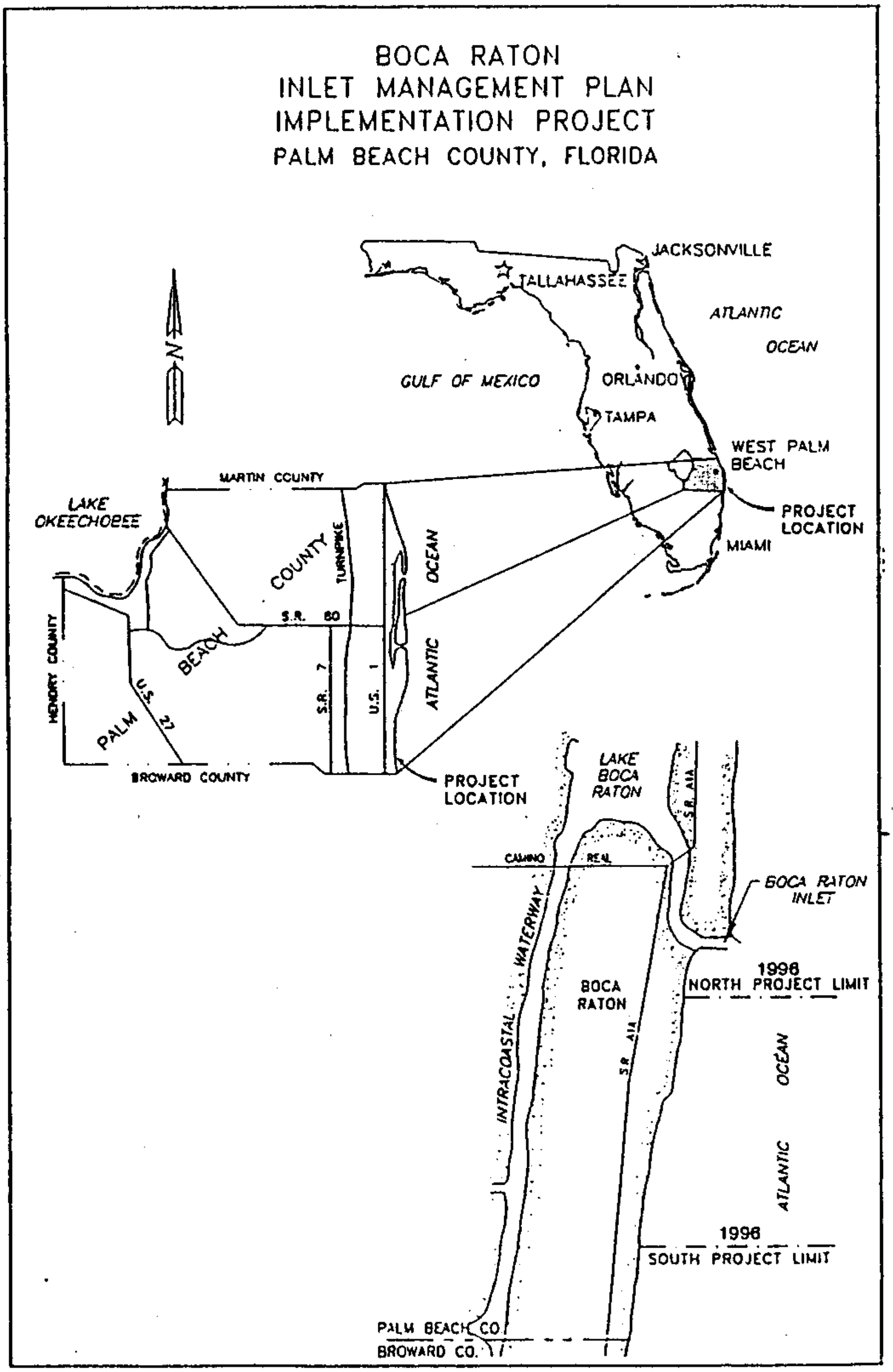
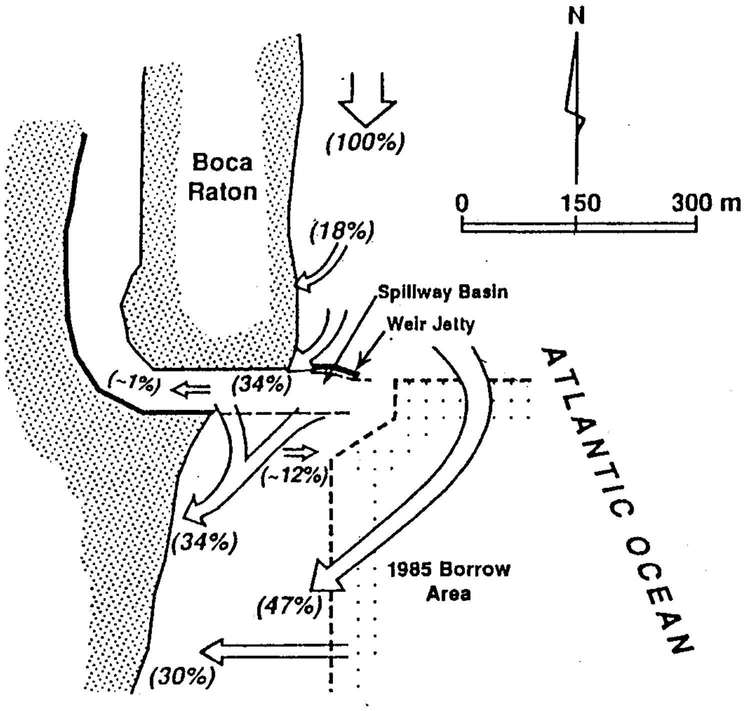


Figure C2: *Boca Raton Inlet Sand Bypassing System (Dombrowski and Mehta, 1993)*



Appendix D

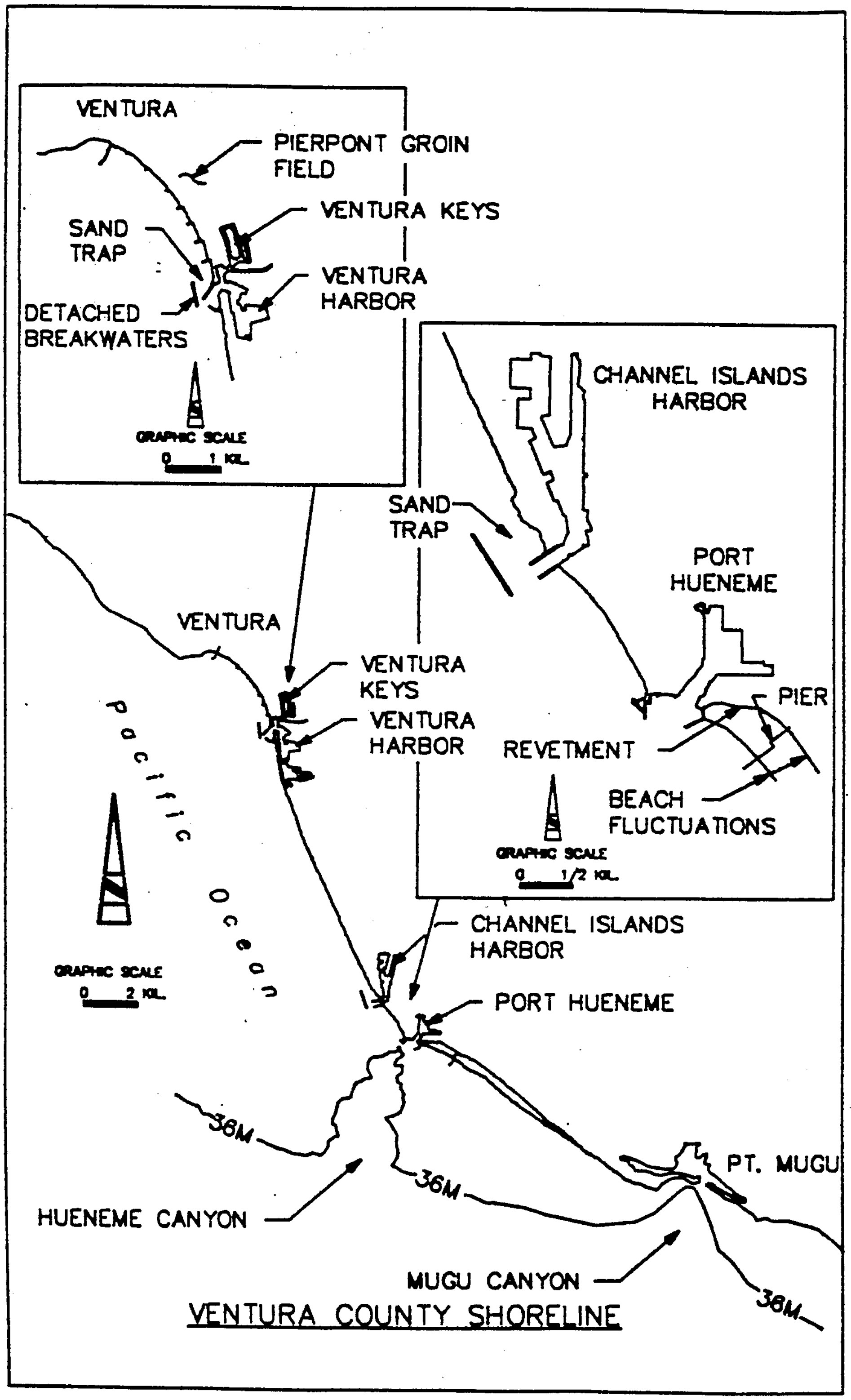
Data sheet: Channel Islands Harbour Sand Bypassing System, California, U.S.A.

Location:	The artificial Channel Islands Harbour was constructed in 1960 and is situated 1.6 km to the north-west of Port Hueneme (pronounced “Why-nee-mee”) in the City of Oxnard in Ventura County, California, USA. The harbour is approx. 60 miles (~96 km) Northwest of Los Angeles facing the Santa Barbara Channel. The area is the coastal edge of the Oxnard Plain, an abandoned flood plain of Santa Clara River which is bound by the Sulphur mountains to the south and the Santa Monica mountains to the north. The Ventura and Santa Clara Rivers are to the north.
Problem:	With the construction of the artificial Port Hueneme in 1938, the southerly drift was halted causing accretion behind the upcoast breakwater and severe erosion downcoast at Ormond Beach threatening Federal, industrial, and residential property. The sand which began to naturally bypass the harbour was lost from the littoral system to Hueneme submarine canyon. Channel Islands harbour was constructed to trap sand which was being diverted offshore into the Hueneme submarine canyon, and to supply sand by mechanical bypassing to Ormond Beach and other downdrift beaches.
Wave climate:	Both the sea and swell are predominantly from the west and north-west owing to restrictions caused by Point Conception and offshore islands. The breaking wave heights common to this shoreline range from 3 - 8 ft (~0.9 - 2.4 m). Some local short duration winter storms and limited amount of summer swell from the South Pacific, produce short periods of northward transport. Wave periods of 14 s or greater often occur in this region (Herron and Harris, 1966). The significant wave conditions used as a basis for design of the offshore breakwater using hindcast data from 1936 - 1938 were : dir = 280° (WNW); T = 6 - 13 s; Hs = 9.4 - 15.7 ft (~2.8 - 4.8 m) at the structure. dir = 215° (SW); T = 7 s; Hs = 10.3 ft (~3.1 m) at the structure. dir = 175° (S); T = 7 s; Hs = 8.1 ft (~2.5 m) at the structure. (Herron and Harris, 1966)
Inlet characteristics:	The man-made harbour has a width of approx. 500 ft (~150 m) and an entrance depth of 20 ft (~6 m) (MLLW).
Inlet usage:	Channel Islands: small-craft (serves up to 1,100 small craft). The harbour is an access point for the islands offshore (i.e. Anacapa, Santa Cruz, Santa Rosa, and San Miguel Islands). (Port Hueneme: deep water US Navy and commercial facility.)
Sediment characteristics:	The Oxnard Plain consists of alluvial deposits of sand, silt and clay.
Drift rate:	Net southerly drift = ~1,000,000 m^3/yr (Walker, 1991) or 1,200,000 cy/yr (Herron, and Harris, 1966) Sources: Santa Clara River = 800, 000 cy/yr (~612,000 m^3/yr); Ventura River = 100,000 cy/yr (~76,500 m^3/yr); littoral drift = 270,000 cy/yr (~206,000 m^3/yr) (Herron, and Harris, 1966)

Beach erosion rate:	Between 1940 (completion of Port Hueneme) and 1961 (establishment of permanent bypass system) approx. 1,000 ft (~765 m) beach recession occurred in the vicinity of the City of Port Hueneme (south of the Port), tapering to no shoreline retreat approx. 7, 000 ft (~2.1 km) downcoast. During this period almost 4,000,000 cy (~3,058,000 m^3) of sand was placed on this stretch of beach between 1940 and 1954. Approximately 500 acres of industrial, residential and agricultural land was lost of a total volume of 21,000,000 cy (~16,100,000 m^3). (Herron, and Harris, 1966)
Type of bypass:	Updrift offshore breakwater sheltered trap with conventional hydraulic pipeline dredging using floating plant moored in and near the entrance, behind the breakwater.
Bypass system components:	<u>1953 -1954</u>: dredged 4,000,000 cy (~3,058,000 m^3) from the fillet upcoast of Port Hueneme Harbour northern breakwater, and pumped under the harbour to southern beach. Project cancelled after only 2,000,000 cy (~1,500,000 m^3) was bypassed owing to difficulties in dredging in the surf. <u>Dec 1958 - Oct 1960</u>: construction of Channel Islands Harbour entrance training walls (finished Sep 1959), and the offshore breakwater (finished Oct 1960). The offshore breakwater is situated in 30 ft (~9 m) depth (MLLW) and is 2,300 ft (~700 m) long with the southern end in line with the southern training wall. <u>Feb 1960 - Jun 1961</u>: initial dredging of Channel Islands Harbour (3,708,500 cy or ~2,835,400 m^3) and sand trap (2,627,000 cy or ~2,000,000 m^3) was bypassed to Ormond Beach by pipeline beneath both Channel Islands and Port Hueneme Harbours. <u>Jun 1963 - Sep 1963</u>: first biennial dredging of the trap, bypassing 1,986,000 cy (~1,520,000 m^3). <u>Apr 1965 - Sep 1965</u>: biennial dredging and bypassing of 3,527,000 cy (~2,697,000 m^3). The larger quantity was dredged to increase the capacity of the trap owing to overfilling and leakage into the entrance since the first dredging project. <u>Apr 1967 - Sep 1967</u>: biennial dredging and bypassing of approx. 3,000,000 cy (~2,300,000 m^3). Again, the large quantity was to increase the trap capacity. It was intended that future biennial bypassing would be reduced to between 2.0 and 2.5 million cy (~1,500,000 - 1,900,000 m^3). (Herron, and Harris, 1966) Walker (1991) reports that the annual bypassing rate has been about 1,000,000 m^3 (~1,300,000 cy) with the majority of the sand going to Ormond Beach and a minor amount going to the beach between the two harbours and backpassed to the updrift beach.
Outlet type:	Pipeline underneath both the Channel Islands and Port Hueneme Harbours to discharge on Ormond Beach.
Bypass rate:	Average bypass rate = 1,000,000 m^3/yr (~1,300,000 cy). Approximately 14,500,000 m^3 (~19,000,000 cy) was bypassed over the first 14 years of operation (Walker, 1991).
Degree of bypassing: (e.g. all, 50%, etc.)	The majority of the sand reaching the Channel Islands Harbour has been bypassed. Walker (1991) suggests that a annual loss of 600,000 m^3 to the Mugu Canyon is occurring.

Costs:	1953 -1954: $1,837,865 (US) for total 4,000,000 cy. Dec 1958 - Oct 1960: $669,000 (US) for training wall construction; $3,351,000 (US) for offshore breakwater construction Feb 1960 - Jun 1961:$1,250,000 (US) for bypassing from sand trap. Jun 1963 - Sep 1963: $951,000 (US) for bypassing. Apr 1965 - Sep 1965: $1,092,000 (US) for bypassing. Apr 1967 - Sep 1967: $500,000 (US) for bypassing. The estimated average annual cost of sand bypassing only, including depreciation and maintenance, was $0.38 (US) /cy. (Herron, and Harris, 1966)
Funding:	US Army Corps of Engineers.
Contract type:	A contract is let for each biennial project.
Owner:	US Army Corps of Engineers.
Operator:	Contract dredger.
Supervisor of operations:	US Army Corps of Engineers.
Staffing:	Dredge crew.
Operating cycle:	Biennial during summer months.
Environmental constraints:	Not known.
Environmental management issues:	Entrance is heavily used for navigation. Beaches are heavily used and backed by beachfront houses and apartments.
Commencement date of bypassing:	February, 1960 with the initial dredging of the harbour and sand trap.
Performance: (include any leakage to inlet, formation of entrance bar, etc.)	The bypass system has performed well with all sand reaching the trap being bypassed (Herron and Harris, 1966).
Present plant status: (as of 1996)	Still in operation.
References:	Herron, W.J., Harris, R.L., 1966. Littoral Bypassing and Beach Restoration in the Vicinity of Port Hueneme California, *Proceedings of Tenth Conference on Coastal Engineering*, ASCE, pp651-675. Walker, J.R., 1991. Downdrift Effects of Navigation Structures on the California Coast, *Coastal Zone '91: Proceedings of the 7th Symposium on Coastal and Ocean Management*, Vol. 1, ASCE, Long Beach, California, USA, July 8-12, pp1889-1903.

***Figure D1**: Channel Islands Harbour Sand Bypassing System (Walker, 1991).*



Appendix E

Data sheet: Dawesville and Mandurah Inlets Sand Bypassing System, Western Australia.

Location: The Dawesville and Mandurah inlets connect the Peel-Harvey inlet system to the Indian Ocean. Mandurah is approx. 65 km south of Perth, Western Australia. Dawesville is approximately 15 km south west of Mandurah.

Problem: Severe algae pollution was caused by poor circulation and increased phosphate levels from agricultural land run-off exacerbated by the low ocean tide range and shoaling single entrance at Mandurah. The construction of the new Dawesville inlet was implemented to increase the flushing and salinity of the Peel-Harvey Inlet system.

Wave climate: Predominantly south-westerly swell.

Inlet characteristics: a. Dawesville: Inlet width = 200 m; depth = 4.5 - 6.5 m below mean sea level at seaward end; water exchange / tidal cycle = 16.5 x 10^6 m^3 (summer) and 17.1 x 10^6 m^3 (winter); diurnal tides.
b. Mandurah: Inlet width = 90 m; depth limited by rock sill to 3 m below CD. Design navigation channel is 30 m wide by 2.5 m deep.

Inlet usage: a. Dawesville: fishing industry and recreational boating.
b. Mandurah: fishing industry and recreational boating.

Sediment characteristics: Clean marine sand.

Drift rate: a. Dawesville: net northerly rate = 85,000 m^3/yr.
b. Mandurah: The littoral drift is understood to vary between 100,000 and 200,000 m^3/yr from west to east without significant reversals in direction. Most of the drift occurs in quantities of 10,000 to 30,000 m^3 during the winter storm events.

Beach erosion rate: a. Dawesville: In 1992, 107,000 m^3 of sand excavated from the channel was placed north of the channel. Between 1992 and 1993 there was a net loss of 90,000 m^3. Since 1993 the volume of sand north of the channel has fluctuated between 100,000 m^3 and 150,000 m^3 less than in 1992.
b. Mandurah:

Type of bypass: Mobile land based system consisting of a crawler excavator feeding a crawler mounted screen and pump system called the “Slurrytrak” (system operates both Dawesville and Mandurah).
.

Bypass system components: 1. Cat 245 Excavator with 3m^3 bucket digging on beach and feeding “Slurrytrak” inlet hopper.
2. “Slurrytrak” consists of inlet hopper with sieves, gravity feeding to a reciprocating tray feeder on to a inclined cleated conveyor with belt weighometer. Conveyor feeds to a linear motion scalping screen on top of agitation hopper which is fed with water (middle and lower). Centrifugal slurry pump fed from bottom of hopper pumps a slurry with approx. 45% sand content by weight through discharge pipe (MDPE and some flexible sections). System is self propelled with diesel motor.
3. Clear water supplied by separate pump via a 315 mm OD Class 12 MDPE pipe from inlet.

At the Mandurah Inlet, a 75 m groyne was constructed in 1986 - 87 approx. 300 - 350 m west of the western entrance training wall to allow for the dredging of a large trap between the groyne and breakwater without affecting the public beach to the west of the groyne.

	At the Dawesville Inlet, a spur groyne was constructed projecting updrift (approx. south) off the southern training wall to create a sand trap behind it.
Outlet type:	A 315 mm OD Class 12 MDPE discharge pipe to downdrift beaches for both inlets. a. Dawesville: channel crossing by 2 fixed pipes trenched in bottom; 0.5km to discharge. b. Mandurah: channel crossing by HDPE line weighted; 1km to discharge.
Design bypass rate:	a. Dawesville: up to 85,000 m^3 pa. b. Mandurah: up to 110,000 m^3 pa.
Degree of bypassing: (e.g. all, 50%, etc)	Desired to be 100%. At Mandurah a bar still exists seawards of the entrance and there is some channel infill during winter storm events. At Dawesville, the trap is not capturing 100% of the sand with accumulation offshore of the trap in depths of -5 m to -8 m CD (approx. 150,000 m^3).
Costs:	In general, bypass operation costs about $3/$m^3$ and monitoring and management costs approx. $1/$m^3$.

a. Dawesville:

Bypassing costs (July to June):

Year	Volume (m^3)	Cost ($)
1995/96	22,000	68,000
1996/97	39,000	103,000
1997/98	85,000	280,000
TOTAL	146,000	451,000
AVERAGE	49,000	150,000

b. Mandurah:

Bypassing costs (July to June):

Year	Volume (m^3)	Cost ($)
1995/96	55,000	179,000
1996/97	156,000	426,000
1997/98	86,000	262,000
TOTAL	296,000	868,000
AVERAGE	99,000	289,000

Funding:	West Australian State Government Department of Transport.
Contract type:	5 year design, construct and operate. Paid per cubic metre (weighed); plus payment per re-establishment; plus guarantee of minimum quantity for each establishment (15,000 m^3 from Dawesville; 20,000 m^3 from Mandurah).
Owner:	Contractor.
Operator:	Local contractor for 5 years.
Supervisor of operations:	Department of Transport.
Staffing:	2 full-time.
Operating cycle:	Up to approx. 48 weeks/year (including maintenance periods) with plant alternating between Dawesville and Mandurah. System is envisaged to operate at each location 2 to 3 times per annum with re-establishments directed by supervisor. System has actually operated 1 to 2 times per year at each site. Minimum quantity for each session as to be 15,000 m^3 (Dawesville) and 20,000 m^3 (Mandurah). Periods of higher sediment inflow at each site are generally not synchronous.

Environmental constraints:	Rock lobster fishing requirement demands a navigation depth of 2.5m LWD from 1 November; main sand infill occurs in winter.
Environmental management issues:	Not known.
Commencement date of bypassing:	December 1995.
Performance: (include any leakage to inlet, formation of entrance bar, etc)	a. Dawesville: trap is not collecting design quantity and is not filling to expected volume; it is believed that there is leakage. Channel has remained relatively stable. Between 1994 and 1996 accretion occurred offshore from the sand trap in depths of -5 m to -8 m CD (approx. 150,000 m^3), reducing sand accumulation in the trap. Offshore bathymetry has since stabilised. b. Mandurah: bar decreasing in volume. The target depth of 2.5 m CD has not been achieved continuously, but access has been provided to most vessels most of the time. Problems stem from insufficient trap capacity during winter storm events. Sand trap has been extended.
Present plant status: (as of 1999)	Still in operation.

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***Figure E1**: Dawesville and Mandurah Inlets Sand Bypassing System, Locality plan (Moloney et al, 1999).*

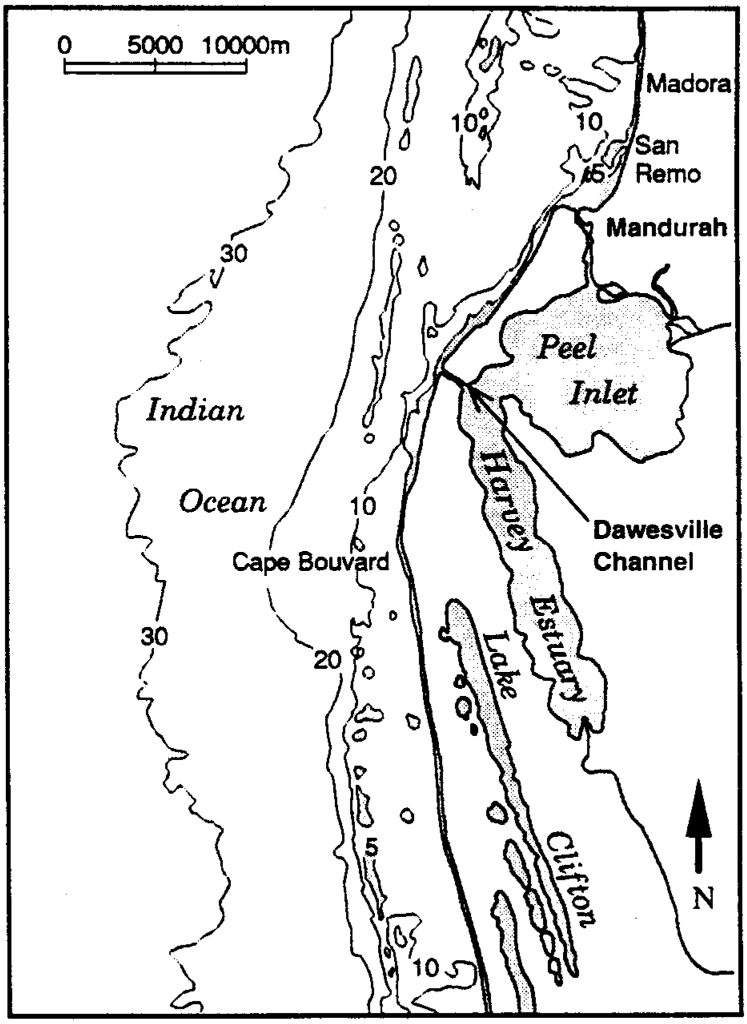


Figure E2: *Layout of Dawesville Sand Bypassing System (Moloney et al, 1999).*

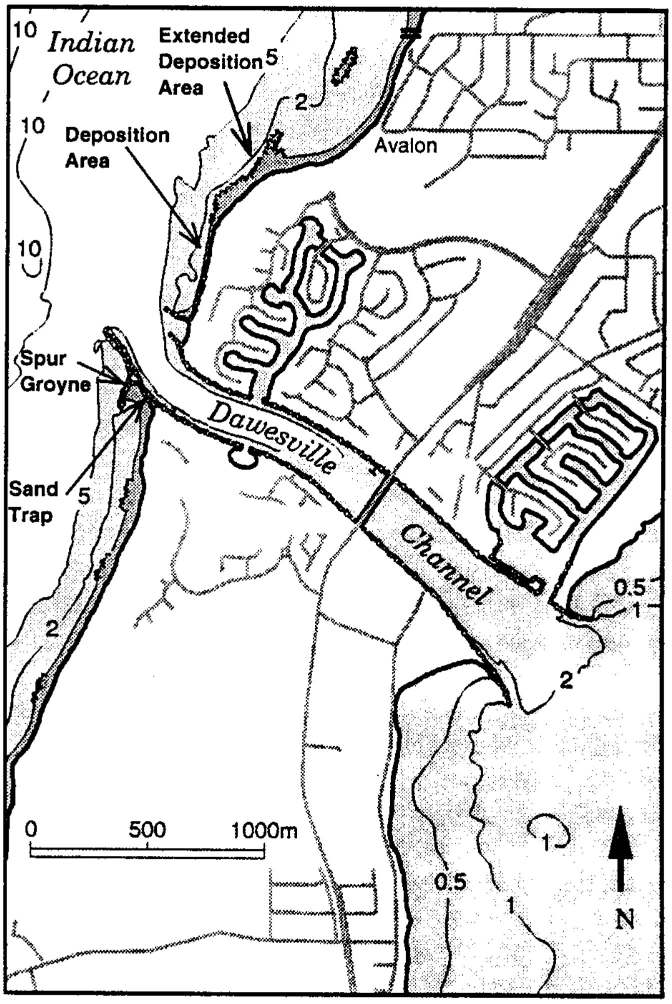


Figure E3: *Layout of Mandurah Sand Bypassing System (Moloney et al, 1999).*

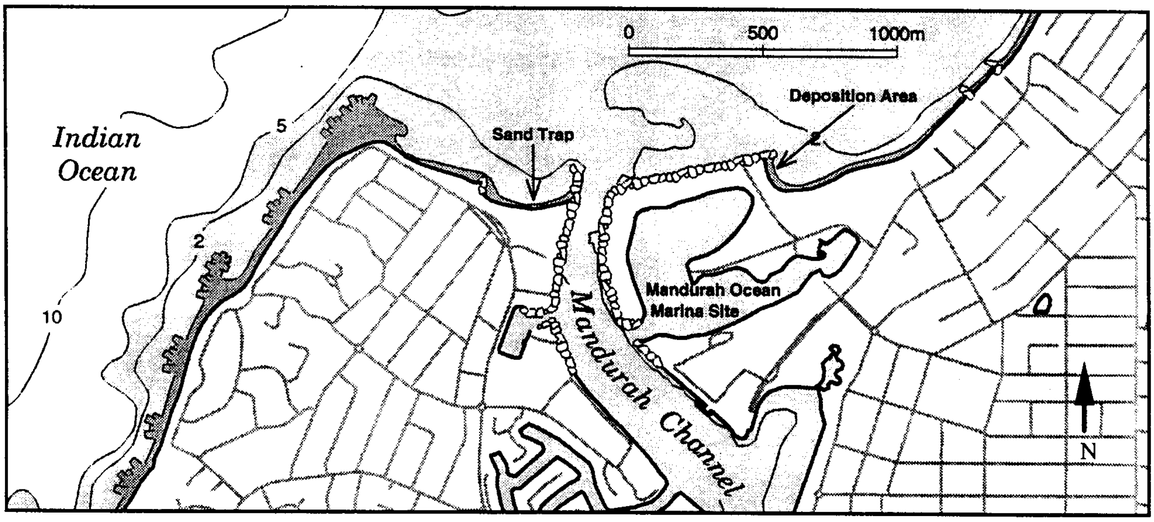
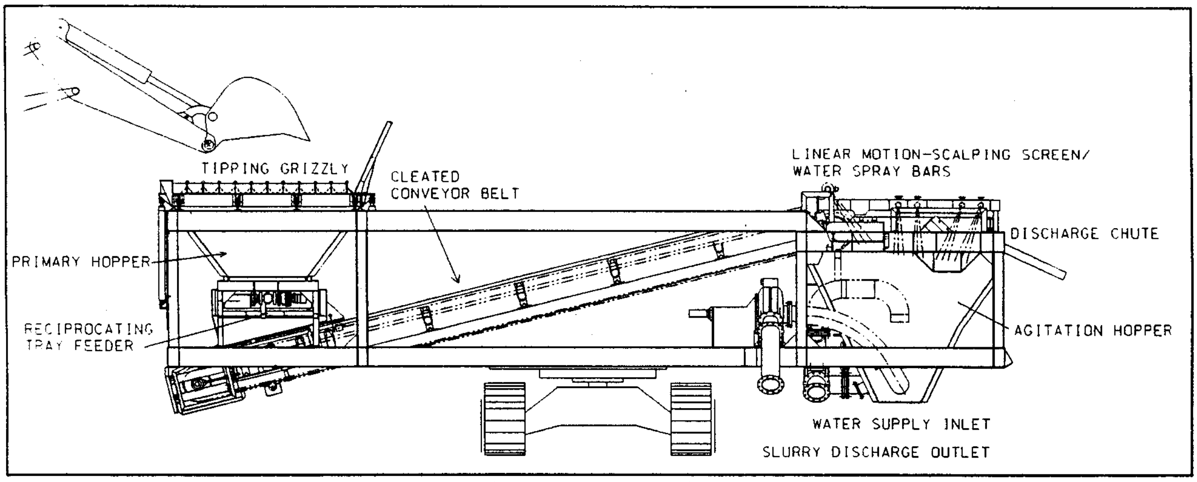


***Figure E4**: General arrangement of the Slurrytrak 300-65 HH used for sand bypassing at Dawesville and Mandurah Inlets (Moloney et al, 1999).*



Appendix F

Data sheet: Indian River Inlet Sand Bypassing System, Delaware, U.S.A.

Location:	Indian River Inlet, Delaware situated on the Atlantic coast approx. 10 miles (~16km) north of Ocean City, Maryland, USA, connects Indian River Bay and Rehoboth Bay to the Atlantic Ocean.
Problem:	Construction and training of the 500 ft (~150 m) wide inlet in 1938-1940 to stabilise the existing channel (which was prone to migrating within a 2 mile (~3.5 km) region, as well as closing occasionally) has resulted in the gradual erosion of the beach adjacent the northern training wall, threatening the Route 1 state highway which runs parallel to the coast line.
Wave climate:	Not known. Calculation of the annual longshore sediment transport rate was based on the use of Phase III WIS (Wave Information Study nearshore hindcast wave data) statistics utilising data from WIS Atlantic Coast Station 65 (Gebert et al, 1992).
Inlet characteristics:	Wall centre line to wall centre line spacing = 500 ft (~150 m); semidiurnal tide; mean tide range = ~4 ft (~1.2 m); spring tide range = ~5 ft (~1.5 m); design channel depth = 15 ft (~4.5 m) MLW; channel dredged to 14 ft (~4.2 m) MLW in 1938 (Anders et al, 1990); existing channel depth = typ. 40 - 90 ft (12 - 27 m) MLW . Channel currents in excess of 9 ft/s (~2.7 m/s) (Anders et al, 1990). *Indian River Bay and Rehoboth Bay*: mean tide ranges = 2.1 ft (~0.64 m) and 1.0 ft (~0.3 m) respectively; combined surface area = 29 square miles (~75 km^2); total tributary area = 250 square miles (~647 km^2). (Gebert et al, 1992)
Inlet usage:	Small commercial and recreational vessels (Gebert et al, 1992, p506).
Sediment characteristics:	Medium sand (Gebert et al, 1992). Typical grain size of the order of 0.4 mm (Anders et al, 1990).
Drift rate:	Net northerly drift of 110,000 cy/yr (~84,000 m^3/yr) based on WIS data, analysis of historic beach profile and hydrographic survey data, and beach erosion data (Clausner et al, 1992). From WIS study: 160,000 cy/yr (~122,000 m^3/yr); std dev. = 90,000 cy/yr (69,000 m^3/yr) (Gebert et al, 1992).
Beach erosion rate:	In the region 200 ft (~60 m) to 1800 ft (~550 m) north of the training wall the shore position has receded 150 - 194 ft (~45 - 59 m) from November 1984 to October 1989 (Gebert et al, 1992, table 1).
Type of bypass:	Single jet pump mounted 135 ton capacity rated crawler crane with 120 ft (~37 m) boom (mobile system) operating from southern beach.
Bypass system components:	Clear water 12 inch (~305 mm) HDPE SDR-9 (9.9 inch or ~250 mm ID) supply line from inlet (approx. 20 m from pump house); water supply pump (8 cyl. motor, 400 hp) in pump house on southern side; Genflo eductor with 2.5 inch (63 mm) nozzle and 6 inch (150 mm) mixing chamber with rate of 200 cy/hr (~153 m^3/hr) positioned in swash zone using Crawler crane; 12 inch (305 mm) HDPE SDR-13.5 (10.8 inch or ~274 mm ID) discharge line; discharge booster pump (12 cyl. motor, 600 hp but running typ. at 400 hp) in pump house; HDPE pipe across Route 1 bridge extending up to a maximum distance of 1,500 ft (457 m) north of the inlet. The jet pump creates an 18 ft (~5.5 m) deep and 48 ft (~14.6 m) diameter crater. The crane can create a trench of three crater diameters length

	before requiring repositioning. Collection occurs over a stretch of the southern beach from 100 - 400 ft (30 - 120 m) south of the inlet.
Outlet type:	12 inch (305 mm) HDPE SDR-13.5 (10.8 inch or ~274 mm ID) pipe discharging directly onto the beach within 1,500 ft (457 m) north of the inlet.
Bypass rate:	Design rate = 200 cy/hr (~153 m^3/hr); 100,000 - 110,000 cy/yr (76,000 - 84,000 m^3/yr). Following experience and system operating enhancements, approx. 330 cy/hr (~250 m^3/hr) can be achieved. The suggested maximum capacity is 552 cy/hr (~422 m^3/hr). Pumping concentration of approx. 40% by weight. Suitable for sites where maximum bypass rate < 150,000 m^3/yr (Watson et al, 1993).
Degree of bypassing: (e.g. all, 50%, etc.)	Proposed to bypass all the northwards transport. However, the system is limited by the quantity of sand reaching the collection area. Strong flow conditions maintains (and are in fact scouring) the inlet depth.
Costs:	Final cost of plant construction: $1.7 million (US) Estimated operating and maintenance: $290,000 (US) (includes annualised replacement costs). The actual operating costs for 1990 to 1996 are given in *Performance* below.
Funding:	Shared between the State of Delaware and the Federal Government of USA. Federal Government contributes 40.755%. .
Contract type:	State performs work for Federal Government.
Owner:	State of Delaware.
Operator:	State of Delaware, which has a state dredging program.
Supervisor of operations:	State of Delaware; oversight by US Army Corps of Engineers.
Staffing:	Total of 3 people: a primary operator, operator's assistant, and crane operator. The staff are supervised by an experienced dredge master (off site) who covers several projects.
Operating cycle:	5 day (7.5 hr day) week (37.5 hr week) with a 2 day weekend shutoff, operating 9 months per year. 1 hr (min) to 7 hr (max.) operation per day. The system operates only 40 % of available days owing to limitations of the amount of littoral material transported and trapped within reach of the system (Watson et al, 1993).
Environmental constraints:	Social: the beach north and south of the inlet is a state park and used by tourists during the summer season. Bypassing is not allowed in summer between Memorial Day (late May) and Labour Day (early September). However, State park service have allowed bypassing during summer months within 100 - 200 ft (30 - 60 m) south of the training wall provided that the area is fenced off and marked with warning signs and buoys. Cold weather conditions and location mean that week day beach usage during the operational window in winter is low; but anglers use the training wall. Surfers also surf adjacent to both breakwaters during the operating season.

Environmental management issues:	The northern beach is a nesting spot for the piping plover, an endangered species of bird, during March through August. Guidelines follow that if a nest is sighted, the discharge operation will stay several hundred feet away, and walkovers will be built to allow young birds to cross the discharge pipe (Rambo et al, 1991).
Commencement date of bypassing:	January, 1990.

Performance:
(include any leakage to inlet, formation of entrance bar, etc.)

Summary of sand bypassing statistics (Watson et al, 1993)

	1990	1991	1992	Total (90-92)
m^3 bypassed	86,000	63,000	51,700	200,700
[cy]	[112,700]	[82,335]	[67,670]	[262,700]
No. Days Bypassing	71	55	60	186
No. Mths Bypassing	11	9	9	29
Avg Production (m^3/day)	1,225	1,150	850	1075
[cy/day]	[1,600]	[1,500]	[1,100]	[1,400]
Avg Days/Month Bypassing	6.45	6.11	6.7	6.41

Short term rate remains about 200 m^3/hr. The higher bypassed amount for 1990 was a result of the initial large volume of trapped sand, and bypassing during summer. As stated by Watson et al (1993), "apparently the system is only able to capture about 60 to 80% of the estimated net northerly drift, though the variable nature of littoral transport in this area makes this conclusion very preliminary".

The rates and operating costs from Feb 1990 to May 1996 for each calendar year (Jan - Dec) as detailed in the additional data for operating expenses were:

Year	cy Pumped	m^3 Pumped	cost/cy	cost/m^3
1990	112,700	86,000	$1.00	$1.30
1991	82,330	63,000	$1.70	$2.20
1992	67,670	51,700	$1.85	$2.40
1993	67,800	51,800	$2.50	$3.25
1994	84,570	64,660	$1.65	$2.15
1995	68,750	52,560	$2.30	$3.00
1996 (partial)	31,550	24,100	$3.00	$3.90

Present plant status: (as of 1996) Still in operation.

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Other data: Indian River Inlet Sand Bypass Plant operating expenses from February, 1990 to May, 1996.

Sand Bypass Plant capital replacement schedule for 1996.

Sand Bypass Plant standard operating procedures.

***Figure F1**: Indian River Inlet Sand Bypassing System (Rambo et al, 1991).*

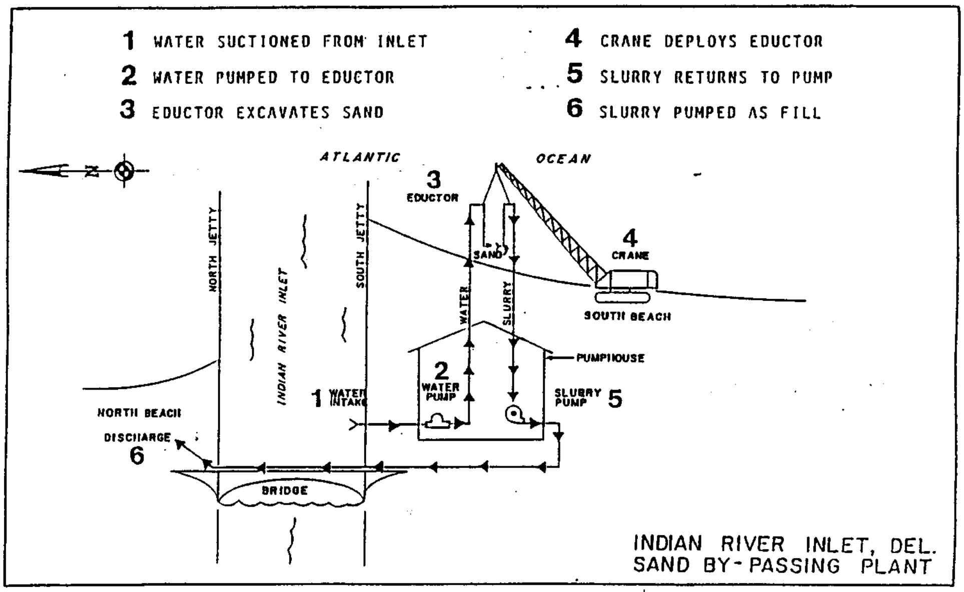
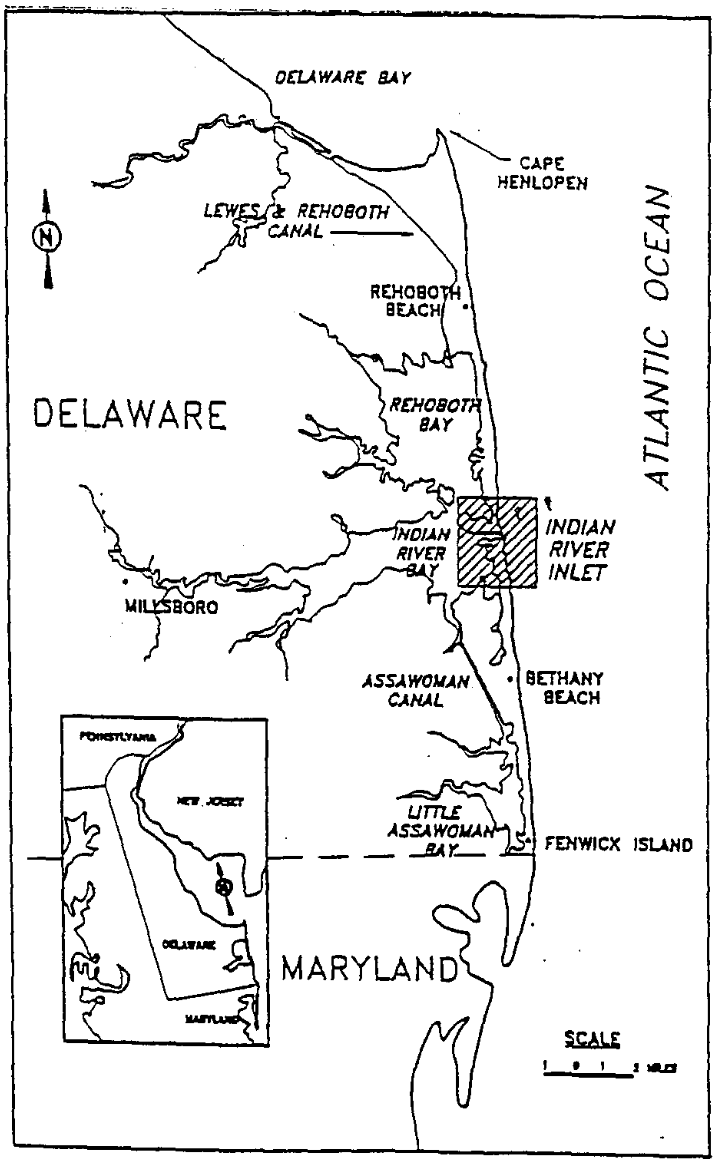


Figure F2: *Indian River Inlet Sand Bypassing System, Locality plan (Rambo et al, 1991).*



Appendix G
Data sheet: Oceanside Harbour Sand Bypassing System, California, U.S.A.

Location:	Oceanside Harbour is situated on the west coast of California, USA, approx. 80 miles (~130 km) south-east of Los Angeles and 30 miles (~48 km) north of San Diego. The harbour is bordered by Santa Margarita River 6,600 ft (~2 km) to the north, and San Luis Rey River 2,400 ft (~730 m) to the south. The City of Oceanside is located to the south of the harbour, and the US Naval Base of Camp Pendelton is located immediately north of the harbour. The harbour services both the U.S. Navy Del Mar boat basin, constructed in 1942, and the City of Oceanside Small-Craft Harbour, constructed in 1963 (with sand dredged from the harbour used to nourish Oceanside Beach).
Problem:	The construction of the harbour complex has interrupted the littoral transport which has resulted in accretion along the northern breakwater, shoals developing in the entrance, and erosion to the beaches to the south (specifically Oceanside beach). The region is also affected by a large gross transport resulting in shoals entering the harbour from both the north and south.
Wave climate:	<u>Camp Pendleton surf and weather station (depth = 32 ft or 9.75 m MLLW):</u> highest measured Hs = 10.8 ft (~3.3 m) with T = 17.8 s Hs(50%) = 3.5 ft (~1.1 m); Hs(10%) = 5 ft (~1.5 m) based on 7 years of data. <u>California coastal data collection program, near Oceanside Pier (depth = 32 ft or 9.75 m MLLW):</u> highest measured Hs = 8.3 ft (~2.5 m) with T = 14 to 16 s Hs(50%) = ~2.0 ft (~0.6 m); Hs(10%) = ~4.0 ft (~1.2 m) based on 3 years of data. Typically, the Oceanside wave climate consists of: <u>Northern hemisphere swell</u>: Hs,o < 10 ft (~3 m); T = 12 - 18 s; Dir = 260° to 270° (November to April). <u>Southern hemisphere swell</u>: Hs,o < 4 ft (~1.2 m); T = 18- 21 s; Dir = S to SE (May to October). <u>Local sea</u>: Hs = 2 - 5 ft (~0.6 - 1.5 m); T_{ave} = 7 s; Dir = predominantly NW (all year). Eastern North Pacific tropical cyclones approaching from the south to south-west (May to November) seldom produce large waves that reach the site. Largest waves at Oceanside occurred in 1939 producing a significant breaking wave height = 24 ft (~7.3 m) (> 100 - 200 yr recurrence interval). (Moffatt & Nichol, Engineers, 1983)
Inlet characteristics:	Tide range: 5.6 ft (~1.7 m) from MHHW to MLLW, or 3.78 ft (~1.15 m) from MHW to MLW (Moffatt & Nichol, Engineers, 1983).
Inlet usage:	U.S. Navy and public small-craft.
Sediment characteristics:	North fillet: D_{50} = 0.21 mm Entrance channel: D_{50} = 0.18 mm
Drift rate:	Net southerly drift = 100,000 - 250,000 cy/yr (~75,000 - 190,000 m^3/yr) Gross transport rate = 1,200,000 cy/yr (~917,000 m^3/yr) (Weisman, 1996) Based on predicted longshore transport rates by three different studies, Dolan et al (1987) presented the following averages: Gross northerly transport = 546,000 cy/yr (~417,000 m^3/yr) Gross southerly transport = 740,000 cy/yr (~565,000 m^3/yr) Net southerly transport = 194,000 cy/yr (~150,000 m^3/yr)

Beach erosion rate:	Camp Pendleton to the north of the harbour continues to accrete, while Oceanside to the south is eroding.
Type of bypass:	Experimental system of jet pumps and fluidisers to be constructed in phases (fixed). Main system location in harbour entrance; secondary capture location at northern breakwater.
Bypass system components:	Phase I: single jet pump (Pekor 6x6x8 inch or 150x150x200 mm, capacity of 330 cy/hr (~250 m^3/hr)) and crane at north breakwater for bypassing sand from the north fillet; two jet pumps (Pekor 4x4x6 inch or 100x100x150 mm, capacity of 230 cy/hr (~175 m^3/hr)) in the entrance adjacent the south breakwater with deployment fluidisers attached to jet pump support beams; mobile hoist barge with pumps (supply pump of 750 hp and main booster pump of 1,050 hp) and controls moving between the north and south jetty riser structures; undersea pipelines to riser structures; cross harbour pipeline; shore booster station (pump of 1,050 hp) used during bypassing of north fillet; discharge line. The hoist barge was a contractor modification due to earthquake/stability concerns regarding jack-up (as designed). Phase II: Addition of 150 ft (~45 m) fluidiser oriented shoreward and parallel to the south breakwater at entrance to feed shoreward entrance jet pump, and 200 ft (~60 m) fluidiser oriented seaward and parallel to the south breakwater at entrance to feed seaward entrance jet pump. The fluidisers are supported on 25 - 30 ft (~7.6 - 9.1 m) spaced steel 12 inch (~305 mm) dia. piles driven in 20 - 22 ft (~6.1 - 6.7 m). The fluidisers are SDR 11 HDPE pipes with 1/8 inch (~3 mm) holes every 2 inches (~50 mm) aligned horizontally, with flanged connections at 50 ft (~15 m) lengths. A valve was introduced into the system to supply firstly to the fluidisers, and then the jets (the supply pump could not support the operation of both the fluidisers and jets at the same time). To improve jet recovery problems, the jets were attached to a 63 ft long (~19 m) strongback (I section) pivoted at a support pile. A fluidiser was attached to this to ease deployment/recovery problems. Phase II contract included operation and maintenance. Phase III (cancelled): Addition of two 200 ft (~60 m) fluidisers to feed sand from the tip of the southern breakwater to both entrance jet pumps; lengthen existing shoreward fluidiser another 145 ft (~44 m); increase entrance jet pumps to 6x6x8 inch (150x150x200 mm); add separate pump to power fluidisers. (Weisman et al, 1996, and Clausner et al, 1990).
Outlet type:	14 inch (~355 mm) HDPE discharge pipe extending 11,000 ft (~3.3 km) to the south along the beach with 3 discharge points along the length. .
Bypass rate:	Ultimately, the system was expected to bypass 250,000 cy/yr (~190,000 m^3/yr) at the entrance and 150,000 cy/yr (~115,000 m^3/yr) from the north fillet (Clausner et al, 1990). Design rate = 200 cy/hr (~153 m^3/hr) (Weisman et al, 1996)
Degree of bypassing: (e.g. all, 50%, etc.)	Only in experimental stages, full bypassing not achieved. It was not designed to achieve full bypassing.
Costs:	Estimated first construction cost of $5,000,000 (US) with a planned project life of 5 years. Actual costs = $15,000,000 (US) approx.
Funding:	Phase I: Federal Government of USA. Phase II: Federal Government of USA. Phase III: Federal with contributions from State and Local Governments.

Contract type:	Phase I: designed by consultant for the owner; fixed price construction contract. Phase II: contractor C & W Diver Services Inc. under contract with payments for maintenance of owners equipment and hire rate for pumping.
Owner:	U.S. Army Corps of Engineers (capital equipment, excluding barge owned by contractor).
Operator:	Contracted out. Phase II contractor C & W Diver Services Inc. under contract with payments for maintenance of owners equipment and hire rate for pumping.
Supervisor of operations:	US Army Corps of Engineers (LA District).
Staffing:	Total of 4 people: main operator to control the SCADA system (Supervisory Control and Data Acquisition); a mechanic overseeing component operations and manual operation of pumps in case of SCADA failure; a shore booster pump operator; and observer at the discharge point (Clausner et al, 1990).
Operating cycle:	Design Plan: 5 days a week, for up to 10 hours per day. Summer months (April - September): bypass from entrance jet pumps Winter months (October - March): bypass from northern fillet. (Clausner et al, 1990) Actual: bypassing only carried out for one year, with approx. 2 weeks only from northern fillet.
Environmental constraints:	No mining allowed of the north fillet on Camp Pendelton U.S. Marine Corps Base Property (rejected by the local base commander) and no mining of the fillet between the south breakwater and San Luis Rey River Groin (rejected by the City of Oceanside) (Weisman, 1996). North breakwater bypass system was placed on the breakwater beyond the intertidal zone without permanent structures as required by Marine Corps restrictions (Walker et al, 1987). Concerns regarding the nesting of the Lesser Tern restricted the operational window to the winter months.
Environmental management issues:	Required to carefully monitor the effects of the system on fauna, fish, plankton, grunion, and other marine species (Walker et al, 1987). Beach outlet required supervision during operation due to 'quick' sand and public usage. Outlet pipes were required to traverse rock walls seaward of beachfront condominiums and lifeguard station at pier, exposing them to wave action.
Commencement date of bypassing:	Phase I: June, 1989 (to August, 1990) Phase II: November, 1991 Phase III: Cancelled (insufficient funds)
Performance: (include any leakage to inlet, formation of entrance bar, etc.)	Phase I (June 1989 to August 1990 excluding January 1990 to April 1990): Total bypassed = 18,300 cy (~13,990 m^3); overall average = 63 cy/hr (~48 m^3/hr); total operational hours = 744; pumping sand hours = 305; minimum monthly pumping hours = 2; maximum monthly pumping hours = 55. Phase II (December 1991 to December 1992 inclusive): Total bypassed = 106,000 cy (~81,000 m^3); overall average = 95 cy/hr (~73 m^3/hr) (58% increase from Phase I); pumping sand hours = 1,128; total system downtime and maintenance hours = 607; minimum monthly pumping hours = 35; maximum monthly pumping hours = 126.

The major problems were associated with clogging and plugging of the fluidisers with sand, and the covering of the craters with kelp which reduced the amount of sand being pumped by the jets. The key problem with this project was that the shoals were forming from transport from both the south and the north, covering a large area to bypass.
(Weisman et al, 1996)

Other significant problems:
(a) difficult conditions for maintenance divers due to long period swell producing a surge in entrance;
(b) inability to access equipment except by using divers;
(c) system was in the entrance adjacent to the navigation channel, providing some constriction to navigation;
(d) funding was not guaranteed for multiple-year operations;
(e) funding was not available (budgets not confirmed) until 1 to 2 months after start of operational window;
(f) equipment was designed to operate at two sites;
(g) expensive booster station.

Present plant status: (as of 1996)

Entrance of harbour had been dredged for many years by conventional suction dredge. Owing to insufficient funding to continue with phase III, the system was closed in 1996 pending removal. At September 1996, documentation was being finalised to call for tenders to remove all of the system. The barge had been removed, and capital equipment on it sold.

Tenders closed 6 November 1996 for the approx. $3 million (US) removal of the bypass system including pipes on breakwaters and to jet pumps, cross channel discharge pipe, support piles, pipe rack, south and north riser structures for jack-up barge, fluidisers, jet pumps. Optional items for removal included the discharge pipe line from the beach south of San Luis Rey River Groin. Items to remain include the booster pump station, discharge pipe between the southern breakwater and San Luis Rey River Groin, and pipes under the southern breakwater spur.

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Figure G1: *Oceanside Harbour Sand Bypassing System locations (Patterson et al, 1991).*

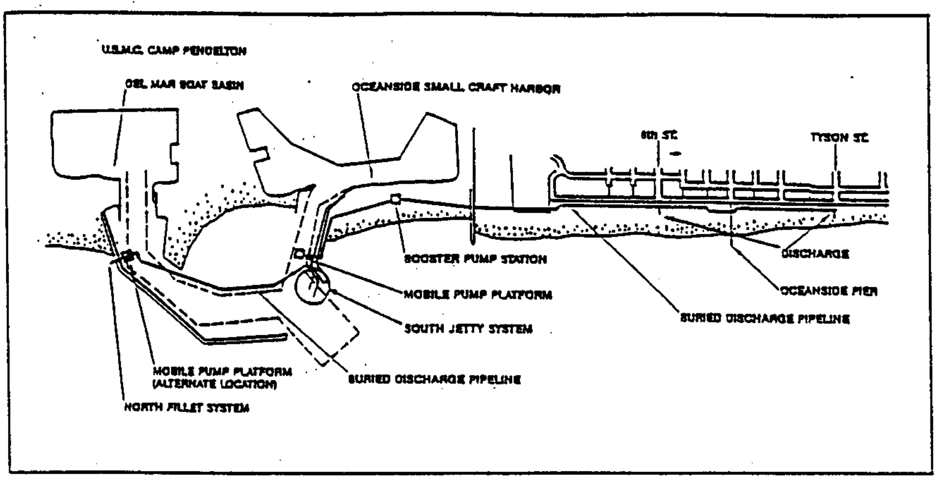


Figure G2: *Oceanside Harbour Sand Bypassing System, Locality plan (Weisman et al, 1996).*

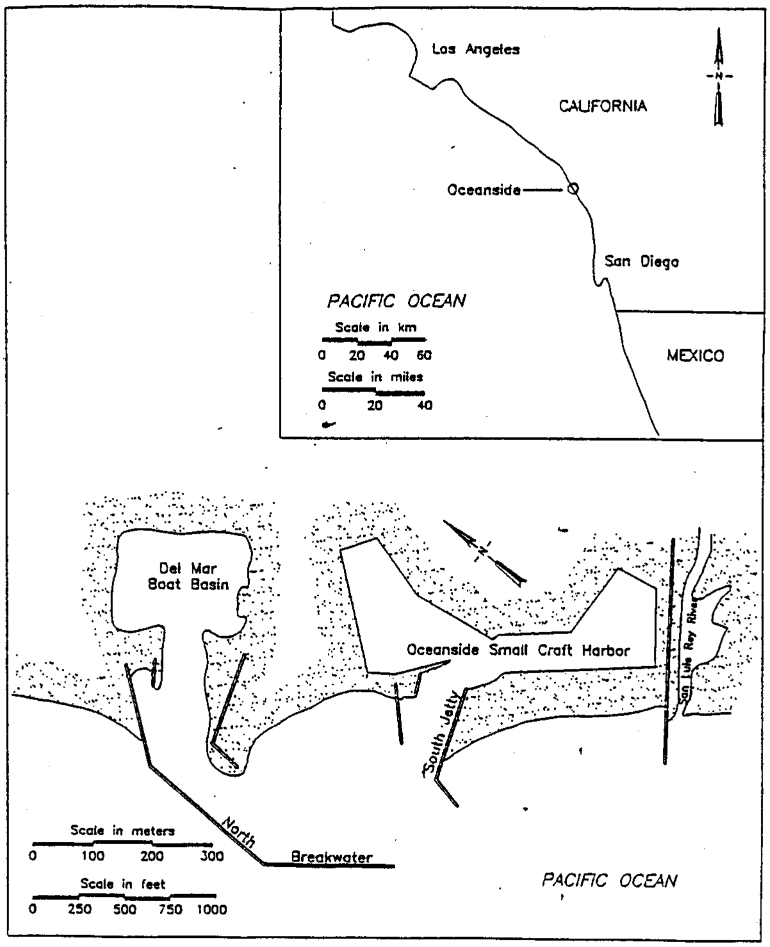
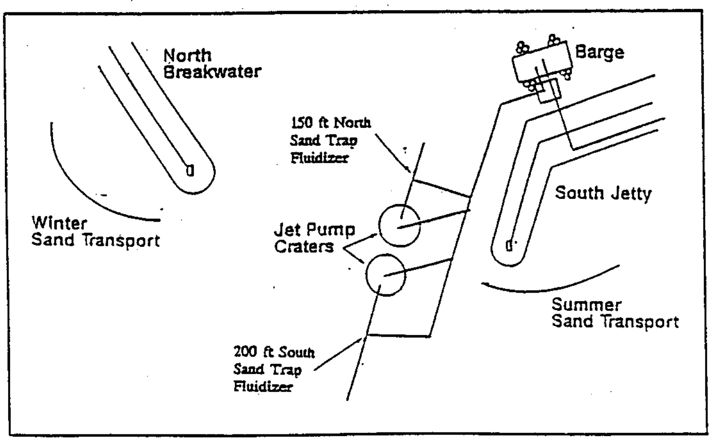


Figure G3: *Oceanside Harbour Sand Bypassing System, Fluidiser locations (not to scale) (Weisman et al, 1996).*



Appendix H

Data sheet: South Lake Worth Inlet Sand Bypassing System, Florida, U.S.A.

Location:	South Lake Worth (Boynton) Inlet is an artificial entrance located in Palm Beach County, Florida, USA, connecting Lake Worth to the Atlantic Ocean. The two adjacent inlets are Boca Raton Inlet 23 km to the south, and Lake Worth Inlet 25 km to the north.
Problem:	The inlet was constructed in 1927 to provide tidal circulation thereby improving the water quality of the Lake. The training walls halted the net southerly transport resulting in erosion of the adjoining southern beach, and also shoaling of the entrance channel from sand moving around the northern training wall. The erosion downdrift threatened upland structures and Highway A1A.
Wave climate:	Varies seasonally; influenced by the sheltering effects of the Bahamas. Strong north-east storms in winter produce the net southerly drift, while more persistent southerly waves generated by local winds occur during summer. Tropical storms and occasionally hurricanes also affect the area (Walker and Dunham, 1977).
Inlet characteristics:	Width varies from 90 m at the entrance to 40 m; depth = 3.0 m (MSL); spring tide range = 3.3 ft (~1.0 m); semidiurnal tides; flood channel flows = 5 ft/s (~1.5 m/s).
Inlet usage:	Small commercial and recreational craft.
Sediment characteristics:	60 % shell; 40 % medium to course sand with significant fractions of quartz and feldspars. Grain size bypassed is slightly in excess of 0.3 mm.
Drift rate:	Net southerly drift = 134,000 - 172,000 m^3/yr (Dombrowski and Mehta, 1990).
Beach erosion rate:	Mean recession rate to approx. 4000 m south of the inlet = 0.9 m/yr with the existing bypass system (Dombrowski and Mehta, 1990).
Type of bypass:	Fixed hydraulic suction dredge with a rotating boom.
Bypass system components:	<u>Initial plant (installed 1937)</u>: 8 inch (~200 mm) suction line; 6 inch (~150 mm) diesel centrifugal pump (65 hp); 1200 ft (~365 m) of 6 inch (~150 mm) discharge line crossing the inlet via the highway bridge. An A-frame derrick on the roof of the pump house enabled the intake to be swung in a horizontal arc as well as raising and lowering. The bypass plant was situated on the northern training wall approx. 50 ft (~15 m) from the seaward end. <u>Upgrade, 1948</u>: 10 inch (~250 mm) intake mounted on a swinging boom of 30 ft (~9.1 m) radius with a flexible rubber sleeve at the centre of the turning radius; jet attached to side of intake for agitating sand; 8 inch (~200 mm) diesel centrifugal pump (600 rpm); 1200 ft (~365 m) of 8 inch (~200 mm) discharge line. The bypass plant can create a circular trench of 8 - 10 ft (~2.4 - 3.0 m) depth and 30 ft (~9.1 m) length with a sand fill capacity of ~800 m^3 (~1050 cy). (Caldwell, 1950; Dombrowski and Mehta, 1990). <u>Upgrade, 1967 (present plant)</u>: 125 m curved extension to the northern breakwater (curved to the south); 20 m extension to southern breakwater; training wall constructed from the inlet to Lake Worth; plant relocated 36 m seaward of the 1937 position (or approx. 100 ft (~30 m) seaward of the MHW line on the north breakwater); 12 inch (~300 mm) suction intake line; diesel Caterpillar engine pump (400 hp) rated to pump 4,000 gpm with 20% solids in suspension; 10 inch (~250 mm) discharge line. (Yeend and Hatheway, 1988; Dombrowski and Mehta, 1990).

Outlet type:	Discharge pipe on to southern beach to deposit between 60 and 150 m south of the inlet. The pipeline crosses the inlet by the highway bridge.
Bypass rate:	Average bypass rate = 53,500 m^3/yr; pumping capacity = 110 m^3/hr (Dombrowski and Mehta, 1990).
Degree of bypassing: (e.g. all, 50%, etc.)	35 % artificial bypassing; 45 % natural (Dombrowski and Mehta, 1990).
Costs:	<u>Initial plant (installed 1937)</u>: installation cost = $15,000 (US). <u>Upgrade, 1948</u>: installation costs = $15,000 - 20,000 (US, 1950 prices). (Caldwell, 1950) <u>Upgrade, 1967 (present plant)</u>: not known The unit price for sand bypassing is $8 - 9 /$m^3$ (US) (Bruun, 1993).
Funding:	<u>Initial plant (installed 1937)</u>: South Lake Worth Inlet District and a property owner. <u>Upgrade, 1948</u>: Palm Beach County. (Caldwell, 1950)
Contract type:	Not known.
Owner:	Publicly owned.
Operator:	Palm Beach County.
Supervisor of operations:	Not known.
Staffing:	2 people for maintenance and operation (Caldwell, 1950).
Operating cycle:	All year round, the operating period being governed by the rate of infill of the bypassing trap. Peak pumping periods occur during September to March (Yeend and Hatheway, 1988). In Caldwell (1950) the plant operated 2 to 3 hours during calm weather, while during periods of north-east weather, pumping for 18 hours still did not match the transport rate.
Environmental constraints:	Not known.
Environmental management issues:	Beaches on both sides of entrance are heavily used.
Commencement date of bypassing:	Original plant: 1937 (ceased operation 1942 - 1945 during World War 2).
Performance: (include any leakage to inlet, formation of entrance bar, etc.)	The plant only bypasses 35 % of the southerly drift with 45 % naturally bypassing via the inlet ebb tidal shoal and bypass bar which attaches to the beach approx. 600 - 900 m south of the inlet. A further 11 % is retained by the northern training wall, and 7 % is deposited on the flood and ebb shoals (2 % of the material entering the flood shoal is dredged and placed on the southern beach). The limitation of reach and capacity prevent a full 100 % bypassing. On only a fifth of occasions does the crater fill faster than dredged (Olsen, 1996). The original design had been for a system with a large boom mounted on rails to give greater trap capacity. The strong velocities produced by the narrow entrance have scoured the

channel to a hard bottom. A bar exists seaward of the entrance.

Present plant status: (as of 1996) Still in operation.

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***Figure H1**: South Lake Worth Inlet Sand Bypassing System, Locality plan (Olsen Associates, 1996).*

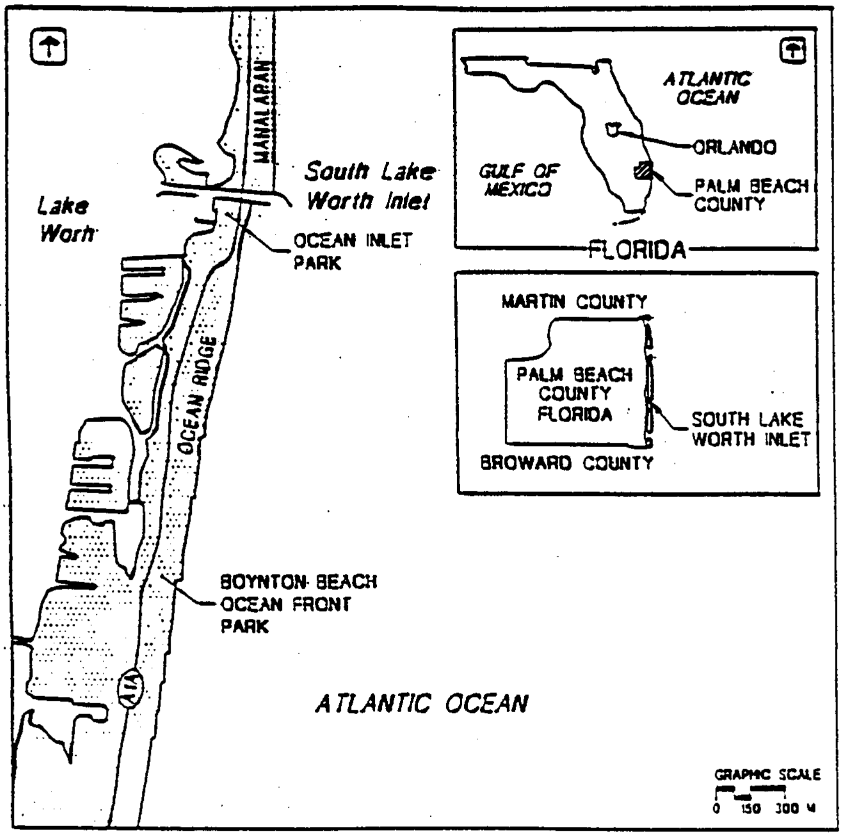

***Figure H2**: South Lake Worth Inlet Sand Bypassing System (Yeend and Hatheway, 1988)*