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Fresh Water to Arabia by VLCC-Fact or Folly?

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FRESH WATER TO ARABIA BY VLCC-

FACT OR FOLLY?

by
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Major Paper

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Professor Bruce Marti

University of Rhode Island
1994

Acknowledgments

To: Kingsmeadow love, power and faith

- 'though the seas are stormy in far horizons, the anchor holds firm:

and

the memory of Chief Engineer James Marshall, Shell Tankers (UK) LTD., a true friend and trusted leader.

ABSTRACT

Population growth, industrial development and the esoteric goals of national self-sufficiency in water and food propels the arid nations of Arabia in a voracious scavenge for alternative resources of fresh water as depletion and contamination of the natural aquifers have reached critical proportions. Desalination of sea water is currently the preferred alternative source of fresh water. Recent misgivings concerning the antroprogenic discharge of desalination effluent (ie. high temperature and high saline water) into the semi-enclosed , epicontinental waters of the Arabian Gulf question the sustainability of this process. Demonstratable deleterious affects of such a process on the marine ecosystem of the Gulf imparts new impetus into the concept of fresh water backhaul by VLCC , a practical alternative source of fresh water. Although suggested over a decade ago, this maritime option was never persued. Recent innovations in VLCC design and the legislative environment in which it operates indicate that conventional VLCCs substantially augment the prospects of such a proposal. By eliciting and combining the deleterious affects of desalination and the virtues of the modern VLCC, this paper attempts to justify the commercial and sustainable viability of the VLCC backhaul of European fresh water to the Middle East.

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CHAPTER I

INTRODUCTION

Arabian Fresh Water Dilemma

Economic expansion and population growth in the arid regions of the Middle East are limited by the availability of fresh water. These regions are among the driest regions on Earth. Fresh water has always been in strict supply, and the sustainability of the region's civilizations is directly proportional to its availability. In 1985, water resources in the twenty-two countries of the Arab world were estimated to be approximately 175 billion m^3, while total water demand was estimated to be about 305 billion m^3. The deficit of 130 billion m^3 is expected to remain constant until the year 2000 (Dabbagh, and Al-Saqabi, 1989). For centuries, the region's demographics demonstrated meager populations in sporadic locations, geographically located to exploit the resources of the few aquifers known to its indigenous peoples. The latter part of the twentieth century witnessed an unprecedented expansion of the Arabic civilization, due primarily to its abundant resources of oil, and the wealth derived from the industrial world's insatiable demands for this resource.

Initial growth was possible only by the over exploitation of fresh water aquifers, resulting in salt water contamination of the fresh water supplies, thus rendering them unpotable (Khalaf, 1985). Spurred by the realization of the imminent collapse of this nonrenewable resource, Arab leaders focused much consideration on the rationalization of consumption and the exploitation of alternative resources of fresh water. Saudi Arabia's ruler, H.E. Mohamad al Faisal, sponsored much unsuccessful research into the feasibility of towing icebergs from the Antarctic to the Arabian Peninsula (Meyer, 1985). Modern technological advances in the desalination of sea water provided the necessary alternative supply. The first such plant was introduced to the Middle East in 1957 (Ali El-Saie, 1993), and today there are over 500 similar plants in the region, producing over 50 percent of the world's 15,582,000 m^3 per day desalinated fresh water production (El-Dessouky, 1994). As demand for fresh water increases, new desalination plants are commissioned. The raw materials of cheap energy and sea water necessary for this process are locally abundant.

Hypothesis

The necessity of fresh water, the very essence of life itself, is undeniably vital to sustain present Middle East populations. Projected and anticipated population and industrial growth can only exacerbate fresh water demand, thus placing increased reliance on desalination, which appears to be the most politically expedient solution to satisfy this demand in the Middle East. But the process of desalination results in an unwelcomed byproduct - - heated, high salinity waste water, which is returned directly to the littoral ocean. The high net annual evaporation rate of sea water from the Arabian Gulf, the reduced fresh water influx (Postel, 1993), and the continued use of the desalination process in the production of fresh water could ultimately result in the shallow, epicontinental, semi-enclosed Arabian Gulf becoming the world's second Dead Sea (Fig.1).

Sustainable development is the contemporary recognition that progress and the ultimate survival of our world and its peoples is acutely dependent on a moral awareness

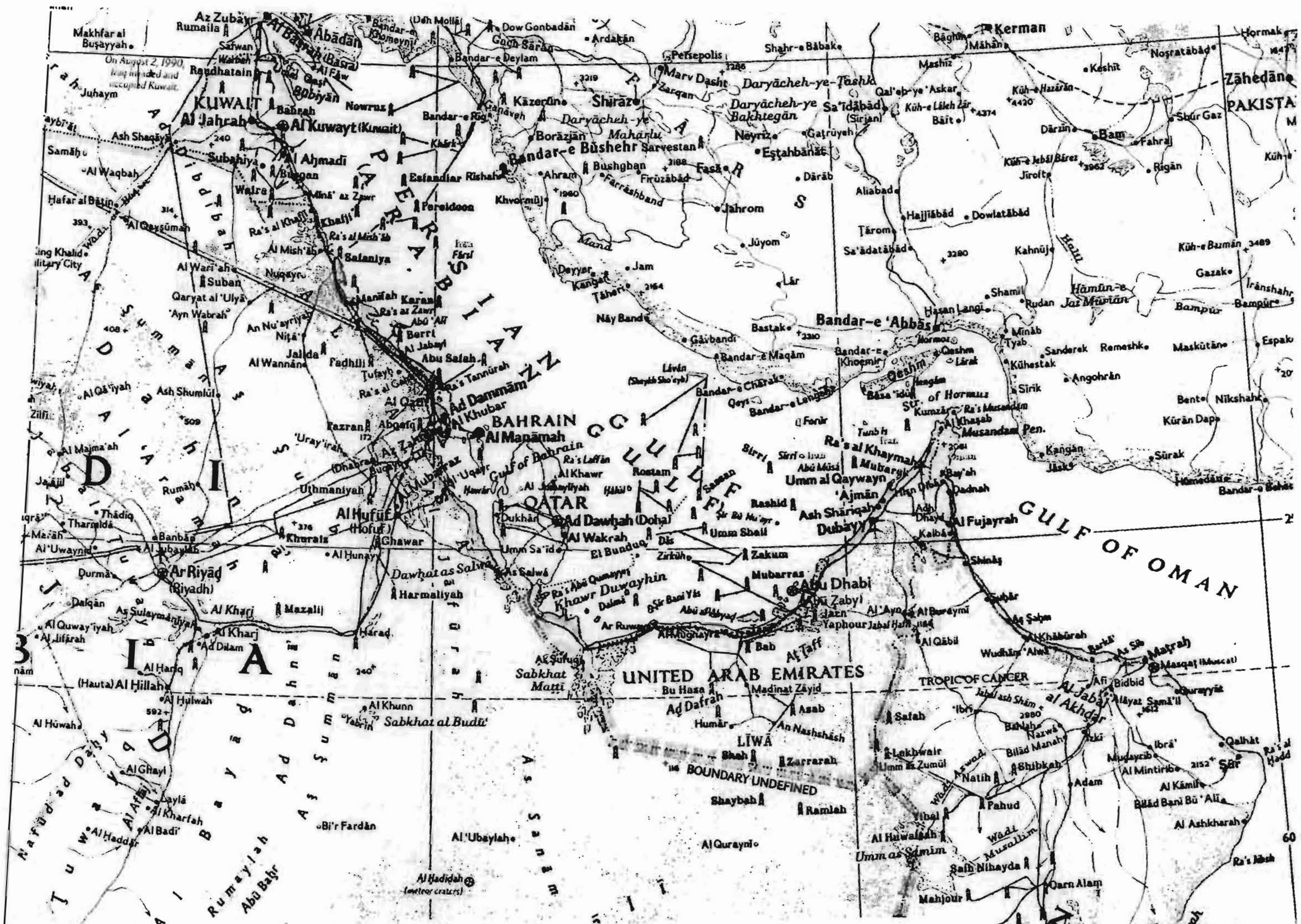


FIG:1 NATIONAL GEOGRAPHIC MAP OF ARABIAN GULF.

and respect for the fragile balances of nature. The waters of the Western Arabian Gulf are already at the ecological threshold for many of its biotic species. The well-being of the waters of the Arabian Gulf, an integral part of the global commons, is of concern to all. The concepts of sustainable development demand that alternative measures be taken to eliminate the dumping and discharge of high temperature, high salinity waste waters in the sea or alternative sources of fresh water be found.

It is hypothesized that the utilization of VLCCs to backhaul fresh water to the Middle East is a viable, sustainable, and commercially sound alternative to satisfying fresh water demand in the Arabian Gulf. The concept of VLCC backhaul of fresh water to the Middle East is not new (Hargreaves, 1985), but the evolution of modern tanker design, together with conventional, operational, and legislative requirements now makes palatable what could not be swallowed in the past.

Methodology

To facilitate the testing of the hypothesis, the following background information is provided to evince the interdependent components necessary for the successful establishment of this maritime fresh water enterprise.

The Availability of European Fresh Water for Export

This study will examine the various areas of fresh water supply and their proximity to the VLCC commercial routes. Do the major oil importing ports of the world have an adequate supply of fresh water? Is this water available in sufficient quantities, and can it be supplied at adequate rates to safely ballast a discharging VLCC?

An assessment of such facilities at Rotterdam, La Harve, Fos/Marseilles, Genoa, and London will determine the necessary facts. These ports are the major European centers of oil importation and by financial necessity, would also have to be the major exporting centers of fresh water. Port and harbor charges are very expensive for VLCCs and operational costs of $20,000 to $40,000 per day are common. Additional delays or diversions for the loading of fresh water could incur an unacceptable financial burden.

An Evaluation of an Islamic Interpretation of Fresh Water From the Christian West

To logically confirm the hypothesis is not entirely sufficient, as significant ideological differences may be detrimental to the final analysis. What may seem perfectly logical to western eyes may prove inimical to Islamic principles of normalcy. Would fresh water from the west, at whatever economic advantage, be acceptable to an Arab? Would the Kuwaiti Oil Tanker Corporation, a major subsidiary of the state-owned Kuwaiti Petroleum Corporation, while embracing the concept of fresh water ballasting, use the resource or dump it? Correspondence with KOTC and other prominent Arabs shall investigate the feasibility of the cultural viability of European fresh water in the Arabian Gulf.

The Modern Ecological VLCC and its Legislative Environment

Recent developments in marine engineering, naval architecture, and international maritime regulations mandating an environmentally friendly tanker have witnessed the introduction of segregated ballast tanks in crude oil carriers, and the almost universal application of double-hull designs. The former assures that no oil cargo can contaminate the contents of the ballast tanks, thereby providing an ideal, high-volume container for the carriage of fresh water. The latter ensures that an inter-barrier space is provided between the outside hull of a tanker and its internal cargo-carrying tanks, thereby providing an extra layer of constructional insurance, in the event of tanker collision or ullision.

Both concepts are utilized and combined in the new European E-3 tanker designed by a consortium of European shipbuilders, with funding from the European

Union. In this design, the double hull has been enlarged to incorporate the segregated ballast space, a clever adaptation of both these ecologically empathetic concepts.

Oceanography of the Arabian Gulf and the Deleterious Effect of the Desalination Process Thereon

Various surveys were conducted in the Arabian Gulf during the twentieth century (National Oceanographic Data Center, 1962). These range from the voyages of Gerhard Schott in 1908, to the recent United Nations Environmental Program's survey conducted by the National Oceanographic and Atmospheric Association of the US in the aftermath of the 1991 Arabian Gulf War (Marine Pollution Bulletin, 1994). An examination of these and intermediate reports should confirm the gradual increase in salinity of the Arabian Gulf. Previous deleterious effects of the byproducts of desalination (i.e., increased salinity and temperature) on flora and fauna of the Arabian Gulf will also be researched. The residual current circulation patterns of the Gulf will be analyzed in order to determine the natural flushing process that currently exists therein.

In order to compare the results of the various oceanographic surveys undertaken in the Gulf, it is necessary to verify if the results obtained by the scientific methodology utilized in 1908, to measure salinity of the ocean, can be readily compared with those obtained by contemporary methods. An examination of the desalination process itself will be presented to confirm the unsuitability of treating the waste product as an effective solution.

It is proposed that the above examination will support the premise that the present method of fresh water production in the Middle East (i.e., desalination) is unsuitable and detrimental to the long-term ecological survival of the Arabian Gulf. This conclusion, if correct, mandates Middle Eastern governments to seek new sources of fresh water. Marine backhaul of fresh water could be such an alternative source.

The Commercial Fresh Water Backhaul Enterprise

The support of the hypothesis necessitates the development of all costs associated with the procurement, transportation and delivery of fresh water by maritime transportation and comparing them with the costs associated with the desalination process itself. This study will attempt to confirm that the rationalization of fresh water supplies, through the utilization of the backhaul concept, is justified on economic terms alone. For Middle East governments, rationalization of fresh water supplies demands that current activities be attained at a cheaper, less costly expenditure or that enhanced activities (i.e., greater fresh water supply) be attained at current expenditures. To determine the associated costs involved, correspondence was initiated with the port directors of the listed ports, the owners and operators of VLCCs, and the central statistical offices of the governments of the countries of the Arabian Gulf region.

The Non-indigenous Aquatic Nuisance Prevention and Control Act (16 USC 4702) 1990, mandates mid-ocean ballast water change for all vessels entering US ports. Article 196, of the 1982 U.N. Convention on the Law of the Sea gives this concept universal application. From a commercial viewpoint, such deballasting and reballasting operations en route to the Gulf would cause additional expense and delays. Fresh water ballasting would alleviate this cost and thus could further support the hypothesis.

Commercial Viability from the Shipowner's Perspective

Commercial justification for fresh water ballast will be demonstrated by an engineering examination of the effects of sea water and fresh water on the highly stressed constructional components of a ship's hull and containment systems. The corrosive effects of sea water are well documented. Their effective elimination in a flexible steel structure immersed in and containing a corrosive fluid is nigh impossible, resulting in expensive protective coatings, frequent inspections and surveys, and very expensive repairs should replacement of steel become necessary during the economic life of the vessel.

Recent developments in ship design have also witnessed the steady reduction in ship scantlings as design techniques become more accurate in the analysis and computations of the maximum stresses therein. This development has effectively reduced the inbuilt structural safety factors associated with older tankers. Therefore, it is essential that stress corrosion fatigue does not become a dominant factor in the progressive deterioration of the ship, as this debilitating condition would rapidly accelerate the natural deterioration process. It is in the shipowner's best economic interest to utilize fresh water as the ballast medium, transporting it free of charge to the Middle East, if need be. It is not suggested that the shipowner be eliminated entirely from direct monetary gain from the transportation of fresh water, but it may be reasonably assumed that such maritime carriage would be very cheap indeed. The extra capital costs involved in providing a double hull are offset by the savings incorporated in less maintenance of structures, less frequent internal hull and interbarrier space surveys and reduced operational downtime.

Clearly, the desirability of a vibrant, healthy marine ecosystem in the Arabian Gulf does have a monetary value. However, this facet is outside the scope of this investigation. The commercial attractiveness and sustainability of the backhaul proposition, and thus the support of the hypothesis, will be apparent with the comparison of the various associated commercial costs and benefits as outlined above.

CHAPTER II

THE AVAILABILITY OF EUROPEAN FRESH WATER FOR EXPORT

Europe's Oil/Water Interphase

Several prominent European ports are capable of accommodating the very largest of conventional VLCCs namely, the ULCC or Ultra Large Crude Carrier (Malpas, 1994). Rotterdam, the Netherlands, is the world's largest port and the destination of most of Europe's imports of 3,878,000 barrels per day of Arabian crude oil (International Petroleum Encyclopedia, 1993). Rotterdam's five oil refineries consumed a total of 102.3 million tons of crude oil in 1992 (Rotterdam/Europort Information, 1994), which amounted to 35 percent of all ocean cargoes handled at that port. Adequate supplies of fresh water are available at VLCC births in Europort, where loading capacities of 10,000 m^3/hr can be provided (Wielenga, 1985). This loading rate ensures that VLCCs can be loaded quickly and safely, as crude oil cargo is being discharged. Rates of 10,000 tons per hour crude oil discharge and simultaneous fresh water loading at a similar rate, would indeed require extra shipboard personnel for complete cargo/ballast management, possibly aided by an advanced computer cargo handling system.

Europe's second largest port, Fos/Marseilles, handled 65 million tons of oil and oil products in 1992 (Malpas,1994), and like Rotterdam, can accommodate the largest of conventional tankships. Moreover, the South of France is replete with fresh water - - a capacity of 6.2 million m^3 per day is available to the region, far in excess of local demand (Port of Marseilles Authority, 1994). An hydraulic network of pipes and canals supply fresh water from the Rhone River and the Alps to the Marseilles region apparently constructed in anticipation of a large future fresh water export market (Bonifacio, 1985). Loading rates of 10,000 m^3/hr are also available at Fos/Marseilles.

The ports of Genoa, La Harve, London and Milford Haven all possess the capacity to accommodate VLCCs, but are restricted in the availability of fresh water supplies, at present (Bloomer,1994, and Malpas, 1994). Should a fresh water export trade significantly develop there is no doubt that these ports could swiftly mobilize the necessary infrastructure to satisfy demand, as nature provides a bountiful supply of fresh water within these port regions.

Economic Logistical Considerations for VLCC Fresh Water Loading

To realize the maximum economic advantage of fresh water backhaul to the Middle East, the oceanic transportation of fresh water must remain subservient, but complimentary, to the primary function of crude oil movement. For supertankers to maintain economic viability in contemporary, low spot rate markets, deviation from the established patterns of crude oil operations would place economic constraints on any such movement. Ships of such magnitude are very costly to operate and berth. Daily operational costs of up to $45,000 are normal for large VLCC operations (Fairplay, 1993 c) and port dockage charges per day at Rotterdam are 0.934 Dfl per Gross Registered Ton of vessel (Rotterdam/Europort Information, 1994). For the 318,013

D.W.T. VLCC, S.S. Lima, with a Gross Registered Tonnage of 153,687 tons (Lloyds Register of Ships, 1990) this translates into:

0.934 Dfl x 0.53 $/Dfl x 153, 687

= $76, 078 (port and harbor dues at Rotterdam)

Therefore, for the economic viability of the fresh water backhaul enterprise, fresh water must be obtained on board ship at very low cost. This mandates that loading fresh water ports and crude discharge ports be synonymous. To derive the customary economies of scale associated with VLCC crude oil movement, supertankers are best qualified to undertake this fresh water enterprise. Therefore, adequate and steady, long-term supplies of fresh water are essential requirements and must be available for loading at the regular supertanker discharge berth. Presently, at Europe's two largest ports, this is a functional reality.

CHAPTER III

AN EVALUATION OF AN ISLAMIC INTERPRETATION OF FRESH WATER FROM THE CHRISTIAN WEST

Water Politics of the Middle East

Predictably, as the oil wealth of Middle East countries accumulates, the powers that be become increasingly obsessed with the possibility of losing it. Human nature therefore, propels matters of security, protection, vulnerability and self-sufficiency to the forefront of regional and national policy decision making. Unfortunately, traditional political instability in the region favors individual nationalistic policies, as interregional issues of the past tended to be more confrontational than cooperative. The multibillion Trans Arabian oil pipeline, built to facilitate Saudi oil exports through the Israeli Mediterranean Port of Haifa, is slowly decomposing in the desert from lack of use, as the Arab boycott of Israel continues. Therefore, it is no surprise to learn of the many individual efforts for self-sufficiency in water, rather than a cooperative interregional approach to this problem.

The Damocles Sword of Thirst hangs forever over the Arabian Peninsula. Water is the source of all life and the lack of it renders the sheikdoms most vulnerable. As natural indigenous resources are precariously depleted, the search for securing self-sufficiency in water is voracious. This is amply demonstrated by the seriousness attributed to iceberg towing research and cloud seeding schemes of recent years (Meyer, 1985, and Hamdan, 1989). Arabic self-sufficiency efforts in food production have attained similar dysfunctional levels. Despite falling agricultural productivity in most countries of the Middle East and widespread drought, government investment in dam and irrigation projects and the cultivation of cereal crops increased through the 1980s, motivated by fears of growing dependence on food imports. Many Middle Eastern governments have been actively promoting a policy of food security and self-reliance as a natural economic goal. This policy is a tremendous drain on limited water resources. In the mid-1980s, Saudi Arabia was the third largest food importer - - in 1991, it became the world's sixth largest exporter of wheat (Beschorner, 1992). Wheat production is heavily subsidized, with guaranteed producer prices several times the world price and estimated annual water consumption of eight cubic kilometers (8 billion m^3). Such pyrrhic policies are symptomatic of Saudi Arabia's unease in its symbiotic relationship with the remainder of the world. Oil revenues were enough to cover the large volume of regional food imports, but economic considerations were outweighed by feelings of strategic vulnerability or the fear of the "food weapon". The drive for self-sufficiency is the single biggest drain on local water resources (Beschorner, 1992). With Arab populations expanding at an average annual rate of 2.2 - 3.7 percent, census estimates of 280 million Arabs are projected for the year 2000 AD (Postel, 1993). The water supply problem will not diminish in the foreseeable future.

Recently, Turkey proposed a "Peace Pipeline" for sharing her abundant water resources with neighboring countries (Dabbagh, and Al-Saqabi, 1989). At a cost of $21 billion, a western pipeline would deliver drinking water to cities in Jordan, Syria, and Saudi Arabia; the eastern pipeline would follow a route supplying Kuwait, Saudi Arabia, United Arab Emirates (U.A.E.), Qatar, Oman, and Bahrain. However, downstream Arab nations do not want to place their water security (the "water weapon") in Turkey's hands or to bank on a technological solution that would be vulnerable to attack in so many countries (Postel, 1993). Turkey's regional reputation was tarnished in 1990 as she diverted the flow of the Euphrates River to fill the Ataturk Dam. This was widely portrayed as a belligerent act in the Arab media, particularly downstream, in Syria and Iraq (Postel, 1993). Yet, Turkey's oil bill in 1990 was $3.5 billion.

A similar plan was given very serious consideration when drafted in the 1950s. This proposal involved piping water from the Shatt-Al-Arab in Southern Iraq the short distance to Kuwait. Unfortunately, a formula for its implementation has remained elusive with very little prospects for revival in the foreseeable future (Dabbagh, and Al-Saqabi, 1989).

At the 1985 United Nations Convention the Nonconventional Water Resources Use in Developing Countries, proposals for the implimentation of fresh water backhaul from Europe by VLCC were presented by an official of Rotterdam's Municipal Water Authority and supported by one of his peer from Fos/Marseilles. These proposals outlined the abundance of fresh water available in Europe, and expressed a keen desire to help alleviate drought in the Middle East by the maritime transport of water thereto. This trade was never initiated despite the apparent attractive economics of the proposition at that time.

The Iconoclastic Nature of Western Water

From a western perspective, the Islamic faith appears strict and didactic with social and formal rules to govern all aspects of human interactions as well as those between God and man. In Islamic law, (known as Sharia), the former are canonized in the Muamalat, the latter in the Abadat. The Sharia, roughly translated as "the path in which God wishes men to walk," regulates every aspect of political, social and private life such as the permissible and forbidden types of food, the manner of a Muslim's dress, and acceptable manners. The assumption underlying the Sharia is that men are incapable of discriminating right and wrong by their own unaided power (Encyclopedia Americana, International Edition, 1989). Social rules are simply the way of doing things in every day life, but they are not generally reducible to formal prescriptions or legal rules or even physical entities (McGlade, and Price, 1993). Islamic law is binding primarily upon individuals, who stand in face to face responsibility with God and is not enforced by the State. Hence, the acceptance of western water would appear to be at the command of the peoples priest, the Mullah, in strict accordance with the Usul-Al-Fiqh ("Roots of law") as prescribed and proscribed primarily by the Koran, then the Tradition of the Prophet if no answer is found therein, and finally, recourse is made of the Ijma, a source of community law as prescribed by wise and pious men of previous generations.

Apparently, western water has past the most stringent of Islamic requirements --it was confirmed by Mr. Adel Abdula Al-Wegayan (Kuwait) that European bottled water (Eau Vivien) is openly on sale in the holiest of Muslim cities, Mecca. All people of non-Muslim beliefs are prohibited from entering this most sacred area (Al-Bahrani, 1994). Thus, Arabic acceptance of potable western water is not iconoclastic to Muslim religious principles, and therefore, acceptable.

The Sharia also provides guidance on sustainable development. Islamic principles provide the rights and privileges of people to use nature's resources, but each successive generation is also entitled to benefit from them. A commitment not to misuse or overexploit natural resources is acknowledged or implied in the Sharia (McGlade, and Price, 1993). Therefore, the over exploitation of aquifers, coupled with the destructive discharge of desalination effluent into the Arabian Gulf ecosystem and obedience to the Sharia appear difficult and dichotomous questions for the ruling families to reconcile. The marine transportation of fresh water to the Arabian nations is a plausible resolution, acceptable to both the laws of Islam and the principles of sustainable development.

1984-1994: A Decade of Change in the Middle East

The swirling winds of change remarkably reshaped the political, commercial and military landscape of the Middle East over the last decade. Iran's fundamentalist anti-western fever has subsided, as it continues to lick its war wounds of the 1980s. The threat of instability in the region from belligerent Iranian actions now appears remote. So, too, with Iraq, as the post Gulf War United Nations blockade continues to isolate and weaken an already crippled country. Iraq's reemergence as a regional power may take several generations following its resounding defeat in the 1991 Gulf War.

Kuwait, Qatar, U.A.E., Bahrain, and particularly Saudi Arabia ought to feel more secure in their own existence following the unwavering western support in response to recent Iraqi aggression. It would appear as though a sustainable peace will prevail in the region for the foreseeable future, as the belligerent kings and bishops have all been reduced to pawns during this decade. Talks of an Israeli/Palestinian peace fan the flames of hope and moderation for the entire brotherhood of Arabic nations. Turkey now sides with Greece as joint members of NATO, and further interdependence is desired, as demonstrated by Turkey's recent application to join the European Union.

The eco-terrorism of the Iraqi Al-Amadi oil discharge brought offers of help, concern and cooperation from around the world, in its assessment, containment, and eventual clean-up (Reynolds, 1993). Cooperative oceanographic research has transmuted local awareness of the Gulf to the international forum with improved understanding of the Arabian Gulf's unique physical oceanography and biota. Such cooperation endorses international confidence in Arabian nations and furthers the principles of functionalism to ameliorate anti-western sentiment, helping to create a rational and trustworthy atmosphere where total self-sufficiency is recognized for its huge waste in resources and wealth.

The winds of change have also reshaped the marine business environment. The hurricane winds of the Oil Pollution Act of 1990 (33 USC 2700 et seq) propelled a new era in oil tanker design and operation. Concern for the maritime environment is now paramount and the "green" concepts of double hulls and segregated ballast tanks are fast becoming ubiquitous in most conventional oil tanker construction (Marine Engineers Review, 1994 b). The 1985 proposal of fresh water backhaul to the Middle East required the transportation of fresh water in empty oil cargo tanks. The emulsification of oil residue with fresh water cargo, and the suspension of oil contaminants therein, required filtering and treatment prior to consumption, thus further increasing its cost. The introduction of segregated ballast tanks has entirely eliminated this problem. An efficient and abundant supplemental source of fresh water is therefore available to the oil exporting countries of the Arabian Gulf. Through the backhaul of fresh water by VLCC, strategic vulnerability considerations are further eroded in the knowledge that many nations of the world posses an overabundance of fresh water. With modest port development in the Philippines, Japan, Dominica, Canada and the USA, alternative fresh water supplies are available (Hargraves, 1985).

CHAPTER IV

THE MODERN ECOLOGICAL VLCC AND ITS LEGISLATIVE ENVIRONMENT

Torpor in Tanker Trades

From its initial introduction in the 1960s, the Very Large Crude Carrier (VLCC) has become indispensable in the efficient maritime transportation of crude oil. The closures of the Suez Canal and the subsequent decades of political instability in the Middle East have polarized awareness of the economies of scale associated with the movement of large volumes of crude oil the long and lugubrious alternative route around the Cape of Good Hope. The new era of the supertanker expanded the frontiers of maritime technology and regulation into uncharted waters -- waters not without peril. Few maritime VLCC disasters occurred in the initial epoch, but those inevitable few were truly world focusing events. Unfortunately, foundering ships of such colossus waged economic and environmental destruction of a proportionate magnitude. To this day, the masters of maritime marketing have failed to sublimate public opinion on the virtues of VLCCs.

The Exxon Valdez disaster of 1989 halted the sporadic evolution of the VLCC, when a trepidatious public demanded serious revision of VLCC design and operations. The new ecological era of the VLCC was spawned as crude oil emulsified the intricate balance of nature's splendor in the pristine waters of the Alaskan wilderness. The political will to implement drastic new designs and regulations, augmented by the economic muscle to enforce such demands, heralded this new "green" era.

The US Oil Pollution Act of 1990 (OPA 90) (33 USC 2700 et seq) was created by Congress which mandated inter alia the installation of double hulls for all new tankers over 5,000 tons, beginning in July 1995, when operating in US waters. Soon thereafter, through regulation 13 (F) of Annex 1 to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto, (Marpol, 73/78), the International Maritime Organization (IMO) gave universal applicability to the US. regulation. At a recent Seatrade Tanker Convention in London, Rear Admiral Henn, Chief of the Office of Maritime Safety at the US Coast Guard, with words that burn, pugnatiously affirmed the Coast Guard's intention of taking an active and aggressive role in carrying out the will of Congress (Marine Engineers Review, 1993). From sorely gained experience, the maritime world knows fullwell such words do not ring hollow.

Double hulls and segregated ballast tanks are standard features of today's new VLCC. The former ensures that an interbarrier space is provided between the outside hull of a tanker and its internal cargo-carrying tanks, thereby providing an extra layer of constructional insurance in the event of tanker collision or ullision. The latter ensures that no oil cargo can contaminate the contents of the ballast tanks, thereby providing an ideal, high-volume container for the maritime transportation of fresh water. The new VLCC owner must now assume the 20 percent increase in construction costs to comply with OPA 90. The cargo carrying capacity of the double hulled VLCC is reduced compared to its single hulled counterpart of a similar length. This translates directly into reduced trading profits for the "green" owner.

A third financial burden is imposed by ports and harbors, as there are no prorated reductions in port dues to reflect lost cargo carrying ability. IMO Resolution A.722 (17) addresses this anomaly, by recommending compensation payable to segregated ballast tank VLCC owners in the form of reduced port charges. The Commission of the European Union plans to introduce a compulsory reduction in port charges for such VLCCs this year (Marine Engineers Review, 1994 a). Several leading European nations have already adopted such a concessionary policy towards "greener" tankers. However, they are very much a minority.

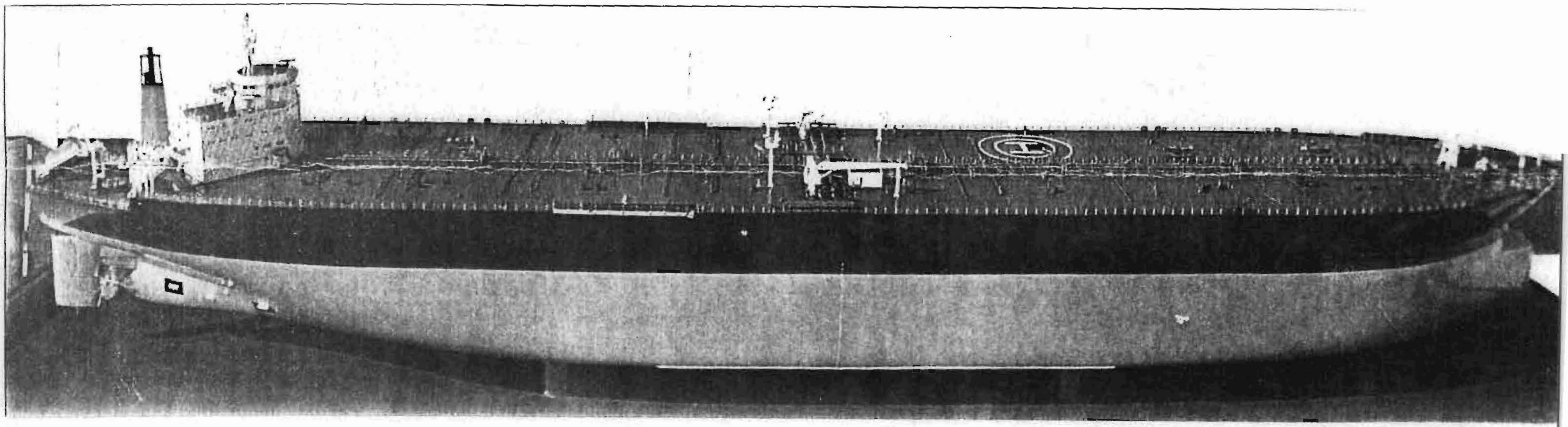
Further financial pressure is imposed on the VLCC owner in the form of increased insurance premiums. OPA 90 mandates certificates of financial responsibility for all owners operating in US. trades and insurance protection of unlimited liability for negligent or willful environmental destruction. Perhaps a realistic insurance premium for such unlimited liability may have been the catalyst in the adoption of the "Green Code" by many of the maritime magnates.

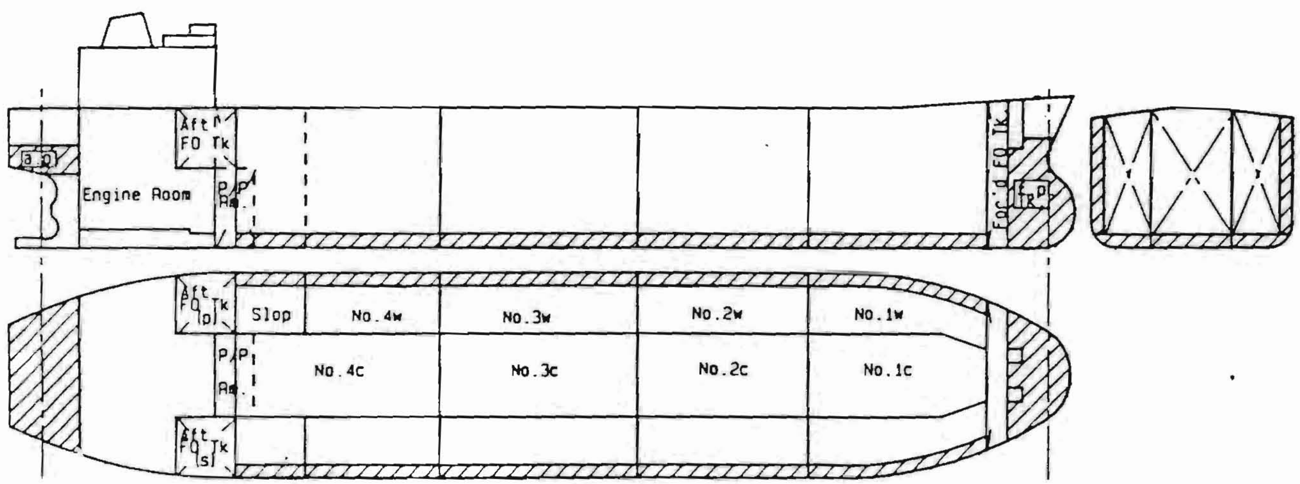
Increased capital and operational costs are presently married with very low charter rates, thus magnifying the financial woes of VLCC owners. With new VLCCs entering service, headlines such as "Crude Oil Market in Throws of Depression" must throw many new owners into throes of discombobulating despondency (Marine Engineers Review, 1994 f). The revival of the liquid bulk market was pegged on the anticipated increase in vintage VLCC scrapings. This has not materialized (Stopford, 1993). Well maintained VLCCs of the 1970s, are perhaps the only profitable crude carriers operating at present (Fairplay, 1993 b). Such ships transport oil for $0.60 per barrel, whereas newbuildings incur a charge of $1.36 per barrel. The vintage VLCC is currently king of the spot market (Stopford, 1993).

Relief of charter rates appear to be a long term gamble as the industrial world still grapples with recession. Instability is further induced as the myopic nations of the oil exporting countries of the Middle East finally embrace the UNCTAD Liner Code's 40:40:20 rule (Juda, 1992). The Kuwaiti Oil Tanker Company, a subsidiary of the Kuwaiti Government owned Kuwaiti Petroleum Company, presently operates one of the world's largest fleets, including VLCCs. Vela International Marine, the international subsidiary of the Saudi Arabian Oil Company (ARAMCO) recently took delivery of the first of six 300,000 DWT VLCCs (Marine Engineers Review, 1994 e). In a separate contract, the National Shipping Company of Saudi Arabia ordered five 300,000 DWT VLCCs from Mitsubishi, valued at $400 million (Marine Engineers Review, 1994 d). The demise of the large Western European oil tanker companies over the last decade has made available a large pool of well qualified and experienced VLCC operators to man these new vessels (Walsh, 1994). With so many new players in an already depressed market, the immediate future does not appear bright. Any financial balm to calm the stormy waters of maritime commerce ought to be audaciously sought and vigorously embraced when presented. Fresh water backhaul presents such an opportunity for the VLCC owner.

The E-Class VLCC

The ecological concepts of double hulls and segregated ballast tanks for VLCCs were recently utilized and combined in the new European E-3 (Ecological, European, Economical) tankers designed by a consortium of European shipbuilders, with research funding from the European Union (Fig. 2). In this design, the double hull has been enlarged to incorporate the segregated ballast space, a clever adaptation of both these "green" concepts (Fig. 3). The ubiquitous embrace of the E-Class design is verified by recent new VLCC deliveries made in Korea, Japan and Europe (Marine Engineers Review, 1994 b). Enlargement of the double hull is necessary in order to accommodate the requisite amount of ballast water for sailing in all weather conditions (Schiff An Hafen, 1992). The E-Class VLCC is typically over 300 meters in length, approximately 300,000 DWTs and endowed with a ballast capacity of over one third its dead weight

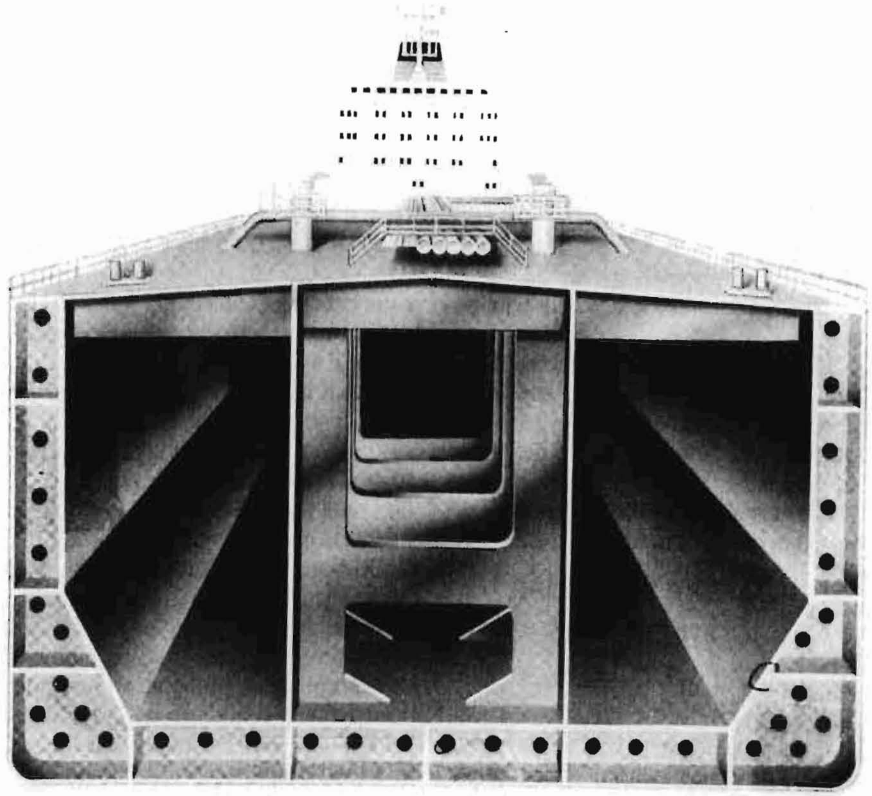




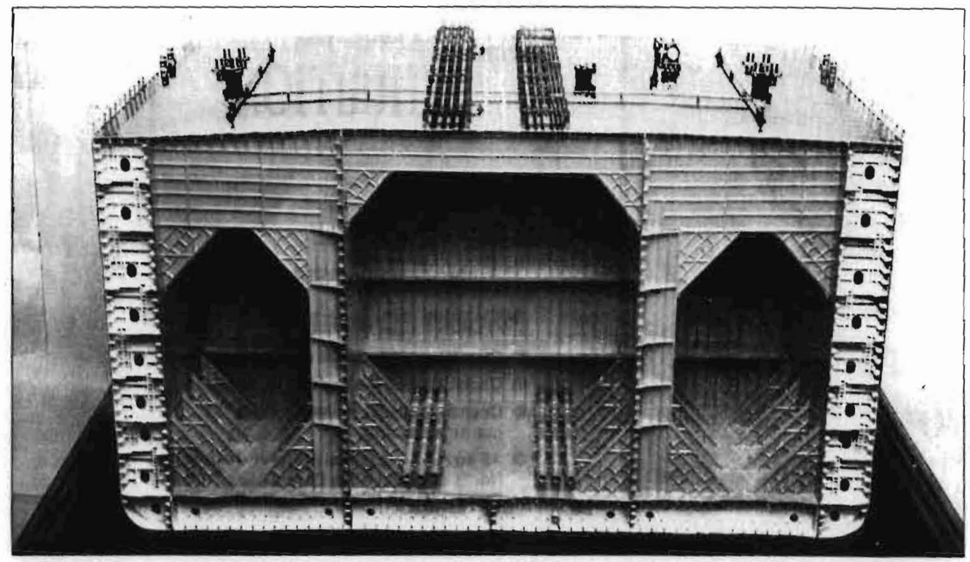
Double skin with two longitudinal bulkheads

FIG.2: THE E-3 SUPERTANKER (ECOLOGICAL, ECONOMICAL AND EUROPEAN).

VLCCs double hulls



E-CLASS MID-DECK SECTION



E-3 MID-DECK SECTION

FIG:3 MID-DECK SECTION OF E-CLASS AND E-3 SUPERTANKERS.

tonnage. Saltwater is the intended ballast medium. For ballast spaces to be adequately protected against the corrosive influence of salt water, the integrity of internal protective coatings is essential. Traditionally, protection against corrosion of water ballast tanks is one area on which shipowners spend relatively small amounts of money and yet it plays a critical role in the premature aging of a ship. As any marine surveyor would confirm, the main enemy and the factor which usually determines the life of a ship is corrosion. Because of their lack of earning potential, ballast tanks are often treated more as an inconvenience, but technical necessity than as a critical part of the ship's structure (Seatrade Review, 1994). The presence of corrosion (general, pitting, and grooving) in ballast tanks has resulted in a reduction of the fatigue life of many, highly stressed, welded intersections of vital components such as deck stringers, shear strakes, webbs, longitudinals, and stiffeners (Bea, 1993). Such components, intermittently submerged in salt water and a dank corrosive environment, are particularly vulnerable in the 0.4 L amidships section of vessels greater than 250 meters in length. Here, any breakdown in the protective coating leads to rapid stress corrosion failure of the affected component. Steel repairs in the vicinity of the double hull would be very difficult and expensive to execute. Therefore, it is essential to confirm the integrity of all structural members and paintwork by visual survey at regular intervals, again an arduous and expensive undertaking for the VLCC owner. Ballast spaces of doubled hulled vessels are critically important as most structural components are contained therein. The traditional laize-faire approach is a luxury the "green" VLCC owner can ill afford. A fresh water ballast medium would greatly reduce the prospects of corrosion, as the rate of corrosion is directly proportional to the medium's electrical conductivity in which it is immersed, and the oxygen content of that medium.

The Minimum Initial Cost Ship

Recent trends in shipbuilding have witnessed a reduction in steel quantity utilized in tanker fabrication. The competitive environment that has been created by shipowners has driven shipyards to design and construct the "minimum initial cost ship" to secure new building contracts (Bea, 1993). This has been achieved primarily by enhanced methods of residual and fluctuating stress level computations within the ship's hull. Over the last 40 years, reductions of 50 percent have been observed in ship scantlings (Bea, 1993). Classification society minimum rule development in the most vulnerable mid-ship section modulus and shear area for a 200 meter tanker demonstrates a 25 percent reduction in section modulus and a 60 percent reduction in shear area during this period (Bea, 1993). Such reductions in steel result in a corresponding reduction in the tolerance to defects and corrosion, not adequately accounted for in many design computations.

Further "improvements" in shipbuilding have incorporated the use of High Tensile Steel (HTS) in areas and components of high stress. Its use in ballast tanks is of particular concern, as it is common knowledge that the fatigue strength of welded HTS structures in a corrosive environment does not increase in proportion to its yield strength. Hence, the higher local strength in HTS components will significantly lower the fatigue life of these components (Shipping World and Shipbuilder, 1993). Again, its use has contributed to the overall reduction in steel used and ipso facto capital savings for the shipowner.

Many new double hulled VLCC owners have stipulated increased scantlings and reduced use of HTS in newbuilding orders (Marine Engineers Review, 1994 b). The E-3's mild steel hull structures are complimented by the judicious and controlled use of HTS, most of which are within the double hull structure. The financial cost involved in the repair of any corroded component would be many times that of a conventional single hulled VLCC, further exacerbating the dearth of financial profitability. The use of HTS again emphasizes the importance of the protective coating and costly detailed inspections during special surveys of the double hull. The relatively primitive types of inspection methods utilized in ship surveys today cannot be very effective in the early detection of fatigue related structural defects. The limitations of the primary method of survey, namely a visual inspection, are self evident. Defect detection is completely dependent on its visual manifestation. This main survey technique is supplemented by hammer testing and the application of penetrating/crack revealing dyes in suspected defects, all, very much, a hit or miss affair. Durability and integrity of initial design and construction in double hulled liquid bulk carriers is therefore essential. Incredulously, and unlike the airline industry, there are no mandatory requirements for non-destructive examinations of key welds during periodic surveys (Porter, 1992).

Durability and integrity of design and construction in double hulls can only be maintained by the application of a durable and resilient paint coating. Such coatings are normally accompanied by five year warranties from date of application and constitute about 1.5 to 2.5 percent of total new ship costs (Seatrade Review, 1994). Internal defects in structural members take approximately five years to visually manifest themselves through a breakdown in paint coating (Brown, 1994). Such warranties, therefore, exculpate the paint manufacturer at a relatively early stage in the life of the vessel. In today's flag of convenience maritime regime, with low crew level ships, it would not be mendacious to suggest that the first five year special survey would be the only human inspection of such double hull interior spaces since commissioning.

With a capital investment of roughly $100 million required for a new VLCC and an operating expense of $45,000 per day, the double hulled VLCC owner requires all the financial resources at his disposal to effectively compete with the refurbished 1970s VLCCs operating at $13,000 per day (Fairlay, 1993 c). Regulation 13(G) of Annex 1, Marpol 73/78, permits the continued operation of the vintage VLCC, subject to its passing classification muster, until it has attained the age of obsolescence, at 30 years. Until such time, the vintage VLCCs dominance of the charter market should persevere.

The carriage of fresh water ballast as a tradable commodity, not only is a potential revenue generator for the shipowner, but can also

a) reduce inspection costs, as surveys should not be required as frequent;

b) reduce significantly repair costs;

c) provide a greater life expectancy of applied paint coatings and ipso facto the prolonged commercial life of the ship;

d) reduce biotic growth in ballast spaces;

e) increase life expectancy of all internal fittings such as gas detectors, valve actuators, pipe supports, sacrificial anodes, pressure and level monitors and other ancillary mountings;

f) render longer inservice operation as reductions in maintenance and repair would significantly reduce dry-dock periods, downtime for exigency repairs and delays associated with minor repairs;

g) save the cost of energy expended in loading ballast water by shipboard ballast pumps if fresh water ballast is used.

Complimentary to the advantages of fresh water ballast is the recent introduction of the new revolutionary zinc silicate marine paint. Developed by NASA, it is presently undergoing extensive field testing in marine applications. This paint has an anticipated extended twenty-five year life span, a huge advantage over conventional five-year warranty paints. Not only does it last five times longer, but a seventy percent savings on painted related expenses are also projected over the life of the vessel (Fairlay, 1993 a).

Double hulled construction also favors the installation of a permanent automatic acoustic emission defect detection system. Fatigue failure, micro-crack development and propagation is normally heralded by sound emission. As steel offers little resistance to sound wave transmission, a series of strategically positioned acoustic detectors at the double bottom center line longitudinal would rapidly detect and locate any crack failure with a sensitivity of 3 mm and above. With over 20,000 longitudinal and traverse web welded connections and approximately 400 kilometers of welded joints in the typical 300,000 DWT VLCC, this inbuilt ultrasonic defect detection system may prove indispensable (Marine Engineers Review, 1994 b). Flags of convenience are ubiquitous. More sophisticated ships are being operated by less technically sophisticated personnel and less of them, at that. The acoustic emission detection system can automatically transmit via satellite, any alarm monitored to shore based technical staff without any shipboard personnel involvement, besides awareness. Such a system would cost in the $250,000 range - - less than the cost of one special survey. It also has the potential of saving millions of repair dollars in the early detection of structural defects (Brown, 1994).

Environmental Legislation and the VLCC

The immense volume of maritime commerce in the Arabian Gulf poses a significant threat to the marine environment thereof (Price, 1994). Being the most abundant resource of crude oil in the world, an estimated 20,000 - 35,000 individual tanker passages navigate the Straits of Hormuz annually in the distribution of oil to the four corners of the world. Tankers return in ballast to the Gulf, water which is duly discharged, as a fresh consignment of crude oil is loaded in the cyclical commercial consummation of their designated maritime purpose. Ballast water is vital to the hydrodynamic stability of a vessel in its unloaded condition. The requisite amount is approximately one third its cargo-carrying capacity. The discharge of such ballast water into the Gulf results in the biota and mariculture of an alien oceanic area being introduced into the Gulf marine ecosystem. New, non indigenous aquatic species are introduced with every deballasting operation. The immense volume of this practice, in this shallow, semi-enclosed sea, increases the probability of the introduction of damaging alien species into this ecosystem with devastating biological consequences. A chilling, yet realistic precedent is admirably demonstrated by the disastrous introduction of the zebra mussel into North American waters as a direct consequence of the discharge therein of a foreign ship's ballast water. To date, this alien crustacean has caused upwards of $10 billion in damages and continues to advance unchecked by natural predators or biological restrictions throughout the waterways and rivers of North America (Carlton,1994). The financial implications for a similar creature to infest the suction intakes of the many desalination plants in the Arabian Gulf would be just as harrowing. Many instances of non-indigenous species introductions have been recorded -- the Codium Fragile and other oriental biota introduced to Auckland Harbor from Japan; California is the new home to Plagusia Dentipes (Japanese common shore crab) from a Japanese semisubmersible drilling platform deballasting operation; the barnacle Megabalanus Zebra from Singapore to New Zealand, and the Caranus Maenas (shore crab) introduced to South Africa under similar conditions (Bercaw, 1993).

The global environmental awareness crusade of the last decade has evolved into a major component of conventional admiralty law. Part of this body of law is the recent US statute on non-indigenous species. The Non-Indigenous Aquatic Nuisance Prevention and Control Act (16 USC 4072), 1990, mandates inter alia mid-ocean ballast water change for all foreign vessels entering US ports by outlawing the discharge of foreign littoral ballast water into the territorial seas and EEZ of the USA. In 1991, the Marine Environmental Protection Committee of the International Maritime Organization (IMO) published recommendations under MEPC Resolution 50 (31) 1991 titled "Ballast Water Guidelines", in recognition of the seriousness of this problem.

Global application of the US regulation is exercised through Art. 196 of the 1982 U.N. Convention on the Law of the Sea (21 ILM 1261) which states:

"(1) States shall take all measures necessary to prevent, reduce, and control pollution of the marine environment resulting from....the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto." (International Legal Materials, 1983).

This article will have binding status with the coming into force of this convention on 16 Nov. 1994. Consequently, tankers will require a salt water ballast change en route to the Gulf, thereby entraining additional operational delays (steamship) and costs (motor ship). Fresh water ballasting would alleviate this burden and ipso facto reduce operational expenditures for the VLCC owner.

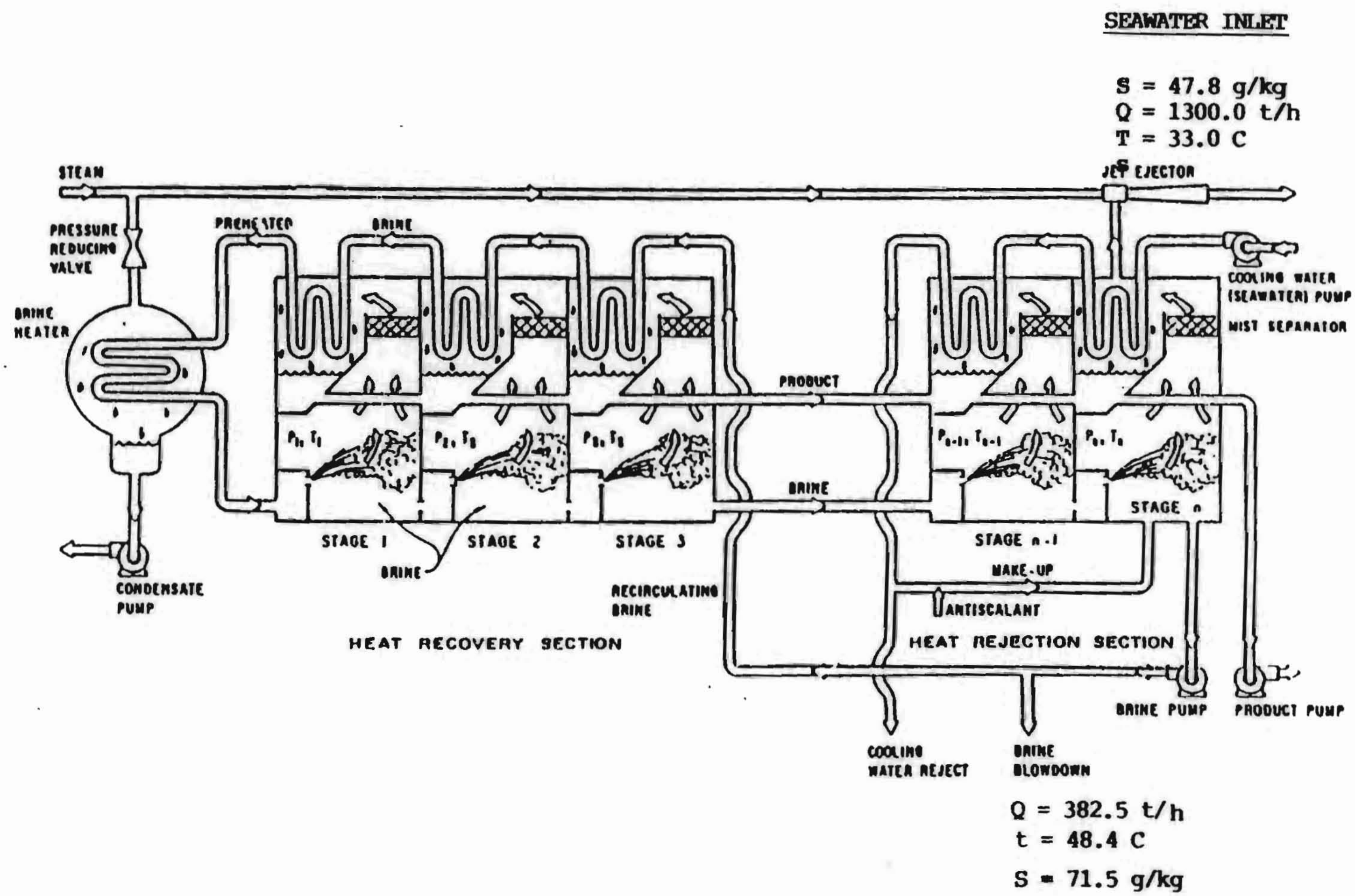
CHAPTER V

OCEANOGRAPHY OF THE ARABIAN GULF AND THE DELETERIOUS AFFECTS OF THE DESALINATION PROCESS THEREON

The Modern Desalination Process

The modern desalination process extracts fresh water from the oceans by the application of modern distillation technology utilized in the Multistage Flash Evaporator (MSF), the Multiple Effect Evaporitic Process and the Reverse Osmosis Process. The most popular process to date is the MSF system - - over 70 percent of all large land-based desalination plants are of the MSF type, and the production of MSF units in the Arabian Gulf countries represent 80 percent of the total product from MSF units in the world (Ali El-Saie, 1993). Consequently, consideration will only be given to the MSF process in this study. Although it is recognized as technological advances in Reverse Osmosis, and the problems associated with the biofouling of its membrane are resolved, this process will gain in popularity due to its more efficient energy use. However, such advances are considered long-term.

With reference to Fig. 4, the MSF plant pumps cool sea water through the condensers of the successive flash chamber distillers where it receives initial heating. Further heating is accomplished in the brine heater from whence it is passed through a



EMIRATE OF ABU DHABI, UAE, WESTERN REMOTE AREAS. NOMINAL SEAWATER INLET AND OUTLET CONDITIONS FOR THE FOUR NEW 1 mIGPD DESALINATION UNITS.

Fig. 4 Typical flow schematic of brine re-circulation MSF plant (courtesy of Sasakura).

series of successive lower pressure boiling chambers. The rising evaporated fluid is then directed through a demister and into the condenser, where the latent heat of evaporation is transferred to the incoming sea water feed, resulting in the precipitation and accumulation of the fresh water product. Finally, this product is extracted to fresh water reservoirs.

The characteristics of the sea water inlet, the brine water blow-down and the distillate produced, as represented in figure 4, are typical of this process and location. The measurements shown represent the operational parameters of the four new one million imperial gallon desalination units recently commissioned in the UAE western remote areas (Michels, 1993). Sea water at a high temperature of 33°C and an elevated salinity of 47.8 g/kg. is pumped through the MSF system to produce fresh water distillate. The brine water blow-down is rejected back into the ocean at a temperature of 48.4°C and an increased salinity of 71.5g/kg. By design, an excess of sea water to fresh water produced is passed through the system to help exchange the elevated brine concentrates remaining once evaporation has commenced. This is a primary defense against the accumulation of precipitated salts and the clogging of the evaporators. A flash range of 40°C is required to produce 0.5 kg. of fresh vapor per 10 kg. of sea water circulated in typical low performance ratio applications. This process therefore requires the circulation of large volumes of sea water (Morin, 1993).

Chemical treatment of feed water is also mandatory in the prevention of hardness salt encrustation of heat exchanger surfaces. Due to the concentrated nature of the heat transfer medium, scaling is the most critical factor controlling MSF productivity (Al-Sofi, Kulaf, and Al-Omaran, 1989). Such compounds as Sodium Sulfite and Polyphosphates are injected into the feed water to foster the coagulation of most of the precipitated salts, thus permitting the excess circulating brine to flush the flocculating sludge from the system. Sulfite pollutants are associated with the well known acid rain phenomenon. Low temperature evaporation is essential as chemical additives to prohibit scale formation associated with increased temperature operation (>120°C) have not yet been developed.

Additional chemical pretreatments include chlorinated biocides to prevent bioaccumulation in heat exchangers, acid injection to neutralize sea water alkalinity and anti-foam tannins to reduce carry-over in the evaporators. As no conventional anti-scaling compound is 100 percent effective, Calcium and Magnesium Carbonate scales do accumulate over time. In most plants, this requires off-load acid cleaning every 6,000 to 10,000 hours, depending on plant design (Ali El-Saie, 1993). The recent development of the on-line Taprogge Ball Cleaning System has increased the operational period between cleanings. The acid cleaning process results in highly acidic waste water, with a pH of 2, being discharged into the sea (Clark, Jay, and Rosenthal, 1970). The shear volume of water involved does not permit for the cost effective treatment of discharged waters.

In conclusion, the MSF desalination process not only produces fresh water, but also results in the anthroprogenic discharge of high temperature, high saline, chemically loaded brine water, supplemented by the sporadic discharge of vitriolic scale consuming toxins, into the littoral Arabian Gulf.

Oceanography of the Arabian Gulf

An understanding of the oceanography of the Arabian Gulf demonstrates the sustainability of the desalination process and its anthroprogenic discharges on this unique biota. The Arabian Gulf is a shallow, semi enclosed, epicontinental sea connected to the waters of the Indian Ocean through the narrow Straits of Hormuz. These straits are barely 56 km. wide at their narrowest point. The Gulf is approximately 990 km. long, from 56 to 340 km. wide, has an average depth of 32 meters, a volume of 8630 km^3, and a surface area of 239 x 10^3 km^2 (Emery, 1956, Lehr, 1983, and Ahmad and Sultan, 1991). Its bathymetric morphology is asymmetrical both longitudinally, where the shallow estuarial waters of the Shat-El-Arab gradually descend to a 90 meter depth at the Straits of

Hormuz, and latitudinally, from the shallow high saline marshes of the Arabic peninsula to the deep waters off the Iranian Coast. Its climate is arid and harsh. Very large temperature variations are encountered both diurnally and seasonally. The borealian monsoon winds, known as shamals, can reach in excess of 100 km/hr during winter months. Very little precipitation occurs, reported at 17 mm per year (El-Dessouky,1994), while the average evaporation rate is 1440 mm per year (Privett, 1959).

Yet Babylonia is the cradle of civilization, the embryo from which it has evolved. Today, these regions are still indispensable to modern ways of life. The Gulf was described in the past as

> "so shallow that any exchange of water between it and the adjacent Gulf of Oman is of small significance. The average depth is only 25 meters and the maximum depth is about 90 meters. It appears to be filled with water of a nearly uniform salinity of roughly 37 g/kg, and some exchange must take place with the waters of the Gulf of Oman, but the character of this exchange has not been examined" (Sverdrup et al, 1942).

Numerous oceanographic studies of the Arabian Gulf since the above report have added much to our understanding of this body of water. Due to the regions bountiful reserves of petroleum and the industrialized world's dependence on this energy source, the Gulf Region is of paramount commercial and military importance. Exploitation of oil reserves and consequent rapid industrialization have transferred the Arabian Gulf into one of the most congested areas in the world. Approximately 60 percent of the world's maritime transport of oil comes from this region (Reynolds, 1994). It is estimated that one ship passes through the Straits of Hormuz every six minutes (Al-Hajri, 1990). Research has revealed that the character of water exchange through the Straits of Hormuz is of a reverse estuarine flow arrangement, and is a significant part of the natural flushing process of the entire Gulf Basin. High saline, low temperature Gulf waters (40.2 g/kg. and 19.5°C) flow into the deep Indian Ocean beneath a top layer of counter-flowing less saline, higher temperature waters (37.1g/kg. and 24.5°C) from the Indian Ocean (Ahmad, and Sultan, 1990). These values are confirmed by the 1992 Mt. Mitchell expedition

(Reynolds, 1994). In Fig. 5, the inflow and outflow laminar flows occupy the top and bottom 30 meters of the water column respectively, separated by a mixing layer of approximately 20 meters (Hunter, 1993). The average annual heat transported into the Gulf is estimated at $24 w/m^2$. This energy gain is necessary to balance the net heat loss due to evaporation and frictional fluid losses (Ahmad, and Sultan, 1991). Observation of these temperature and salinity values indicate that the "engine" necessary to cause natural circulation in the Arabian Gulf is both salinity and temperature (hence density) driven, the predominant power being salinity. In the Gulf proper, this thermohaline circulation is augmented by a Coriolis Force caused by the earth's rotation, and more significantly, by the surface currents induced by the monsoon shamal winds. Due to the shallow nature of the Gulf, the entire body of water is within the Ekman depth of frictional influence. The dominant surface circulation is shown in Fig. 6 (Reynolds, 1993). This circulation pattern is confirmed by Hunter, 1984 and Lardner, 1993, in Fig. 7.

The only significant fresh water input into the Gulf is from the Shat-El-Arab estuary. As Turkey completes its GAP project of dams and irrigation schemes severely curtailing the flows of the Tigris and Euphrates Rivers, and Syria and Iraq extract an ever increasing share of the remaining water, it is proposed that the net fresh water flow into the head of the Gulf will seriously diminish in the foreseeable future (Postel, 1993). Presently, outflow from the Shat-El-Arab is carried by the counter-clockwise circulation in a westerly direction, thus diluting the saline waters off the coasts of Kuwait and Saudi Arabia and assisting in the flushing action of this littoral zone (Reynolds, 1994). Note also the similarities of bottom currents as portrayed by Hunter and Lardner in Fig.7.

For the main body of Arabian Gulf waters, the dominant forcing mechanism of residual currents in the Gulf is through pressure gradients arising from evaporation induced density variations. Horizontal variations in water density give rise to horizontal pressure forces which vary with depth. The resultant circulation (Fig. 8) produces water

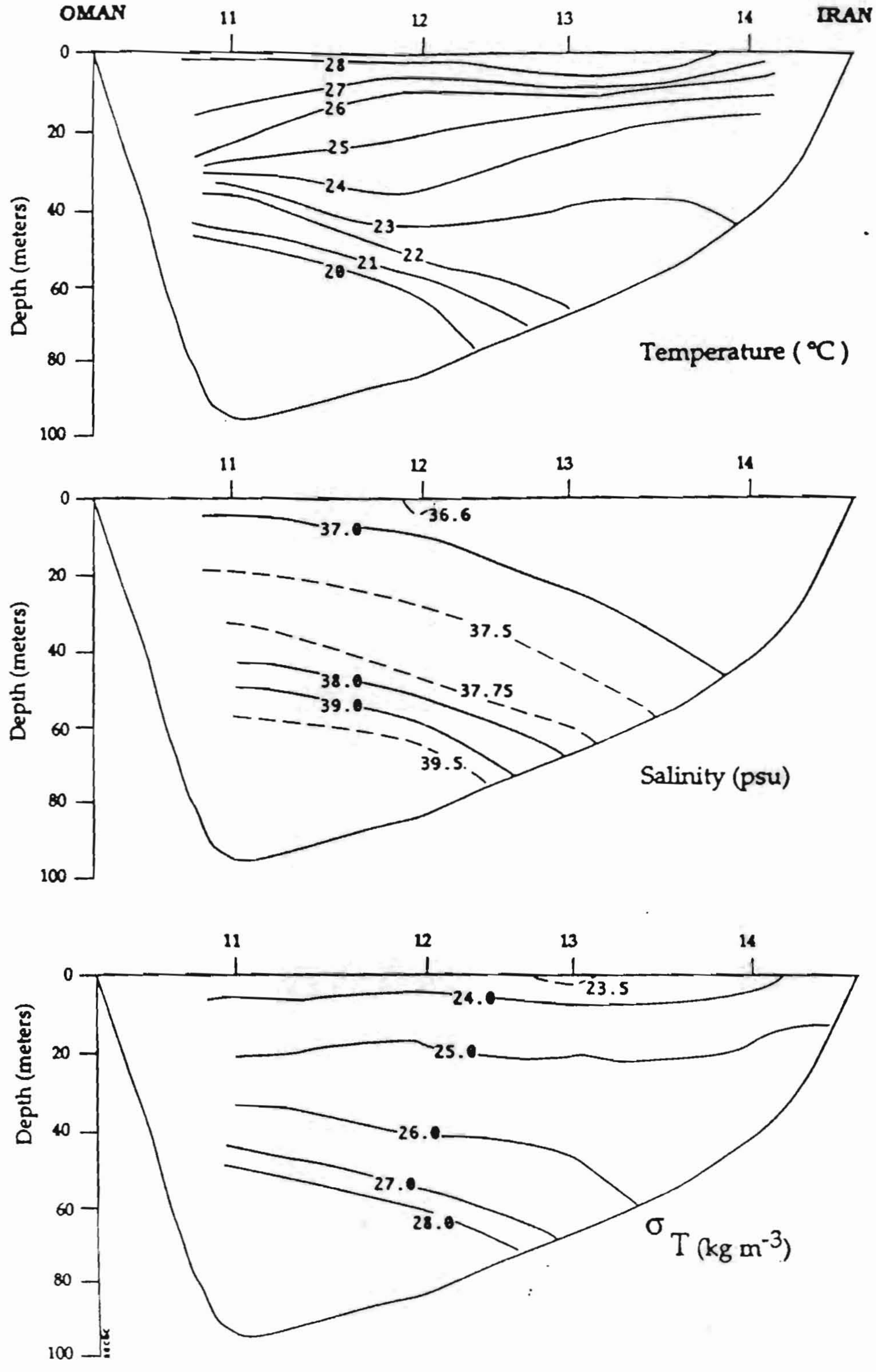


FIG. 5 CTD cross section across the Strait of Hormuz, 1993 (summer).

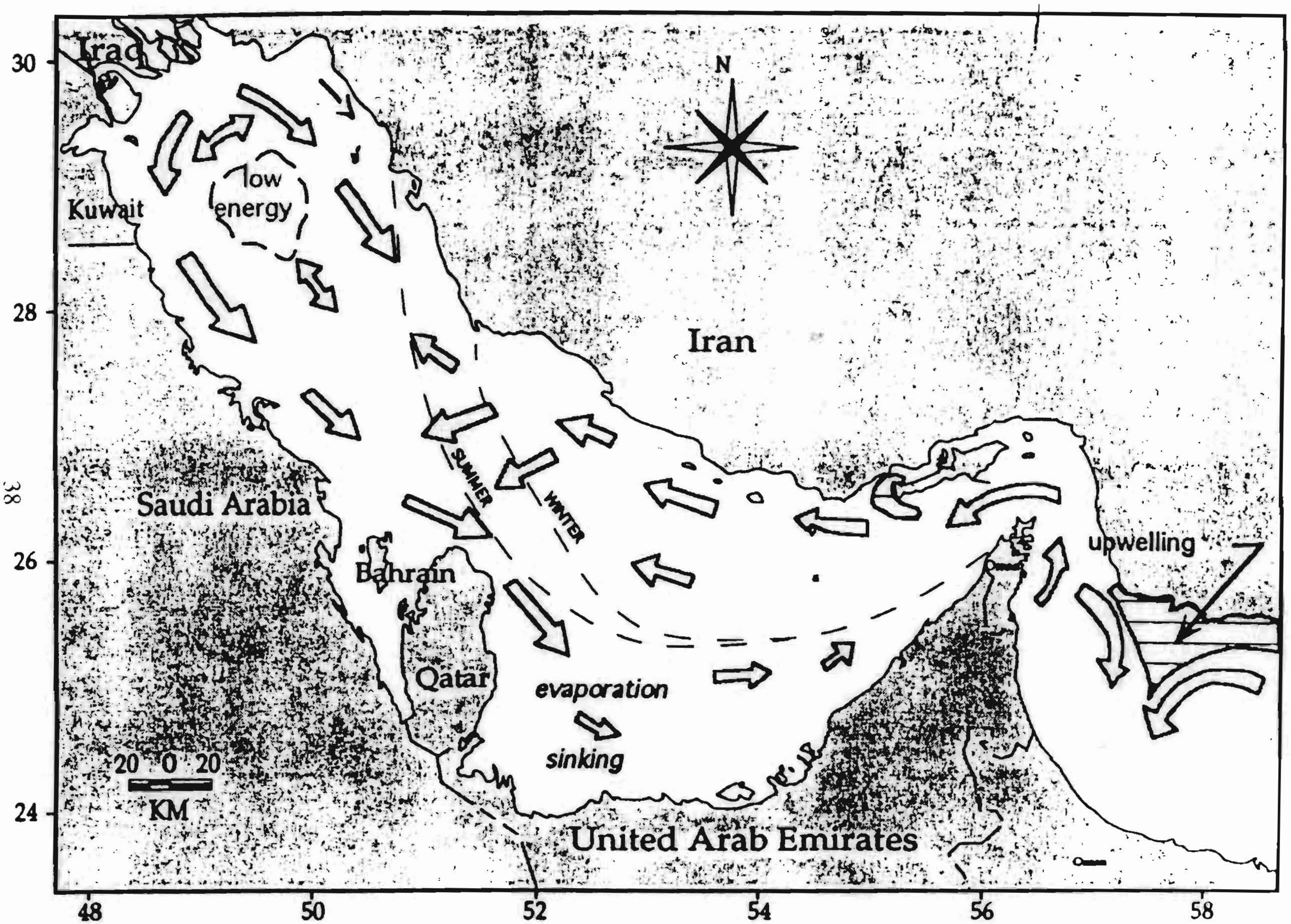
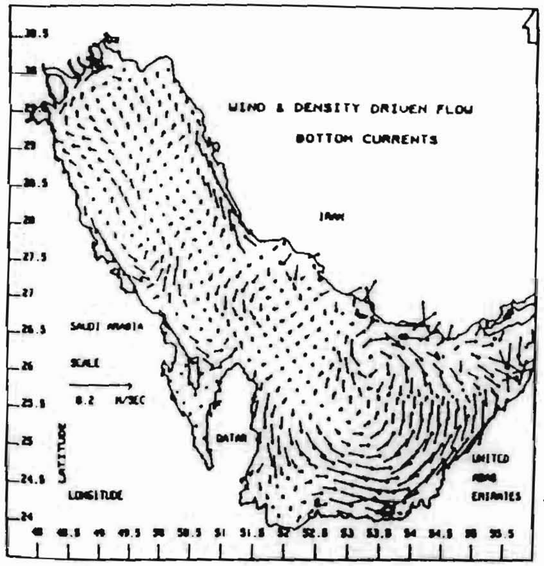
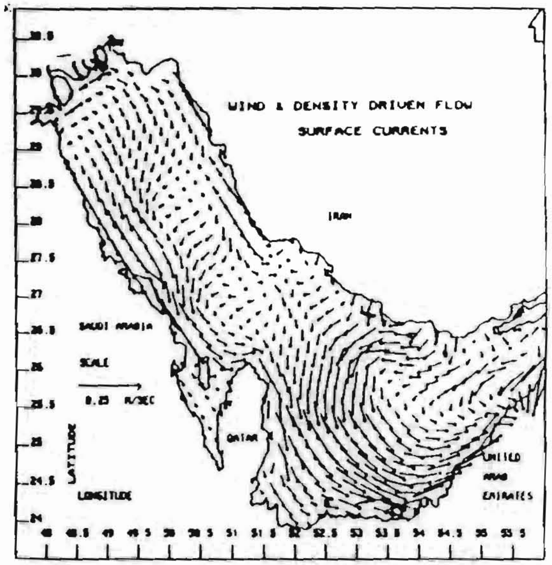


Fig. 6 Schematic of surface currents and circulation processes. (REYNOLDS 1993)

LARDNER 1993

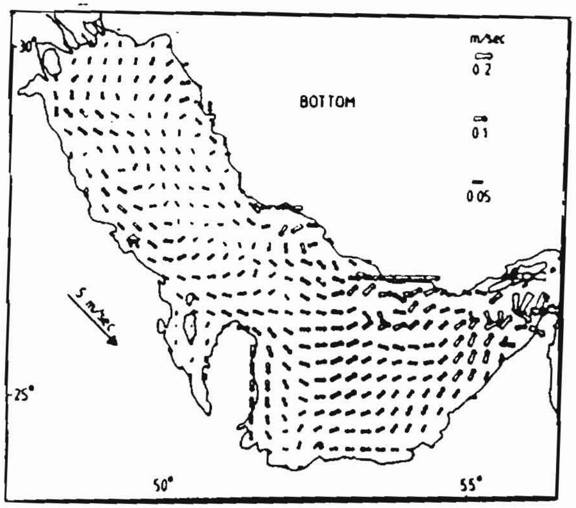


Computed bottom flow driven by the average June wind combined with the density gradients from Leg 6 of the *Mt Mitchell* cruise.



Computed surface flow driven by the average June wind combined with the density gradients from Leg 6 of the *Mt Mitchell* cruise.

HUNTER 1983



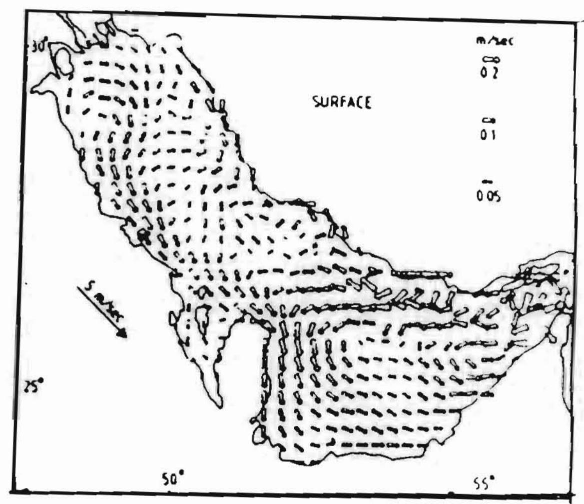


FIG. 7 COMPUTED BOTTOM AND SURFACE CURRENTS OF ARABIAN GULF: LARDNER 1993(top); HUNTER(1983) BOTTOM.

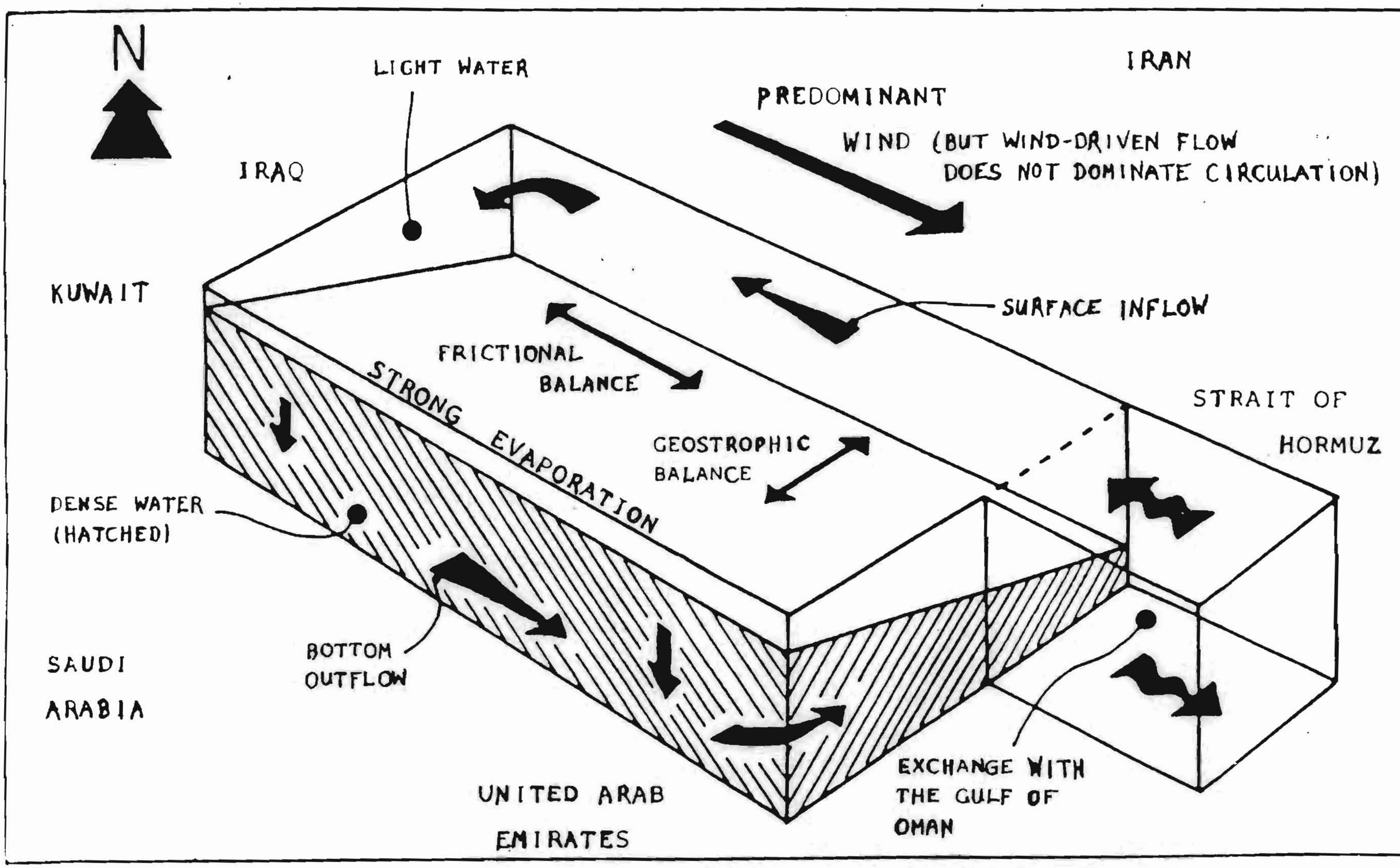


Figure 8 The probable circulation pattern in the Gulf (after Hunter, 1982).

movement in and out of the Gulf, and it is calculated that the flushing time (time for water in the Gulf to be exchanged with water from the open sea) is 5.5 years for a 90 percent transfer (Hunter, 1983). In close agreement with Hunter, (1983), Reynolds concludes that:

a) The ocean water inflow current along the Iranian Coast is weakened by Shamal winds in the winter, and in the summer, with the reduced energy of the Shamals, this water extends almost to the head of the Gulf.

b) A cyclonic circulation gyre fills the southern Gulf and is driven by the inflowing surface waters through the Straits of Hormuz. The surface current is predominantly density driven.

c) A southward coastal flow is present along the entire Southern coast of the Gulf. This surface flow stagnates east of Qatar where high evaporation and sinking forms a dense bottom flow which is deflected to the Northwest by Corioli forces and out through the Straits of Hormuz (Reynolds, 1993).

An examination of oceanographic research in the summer Arabian Gulf by Schott, 1910, (Fig. 9); Shultz, 1914, (Fig. 10); Emery, 1956, (Fig. 11), and the 1992 Mt. Mitchell Expedition, (Fig. 12), reveals the relative stability of salinity in the Arabian Gulf over time (National Oceanographic Data Center, 1962, and Reynolds, 1994). The isohalines of the former three compare favorably with the halocline of the recent Mt. Mitchell findings. Of particular interest is the 39 g/kg isohalines along the central Gulf axis and the 39 g/kg. halocline of the Central Gulf cross-section in Fig. 12. This examination reveals that salinity levels in the major water body of the Gulf have not altered significantly in the period from 1910 to 1992. But are the salinity measurements of the early twentieth century reliable?

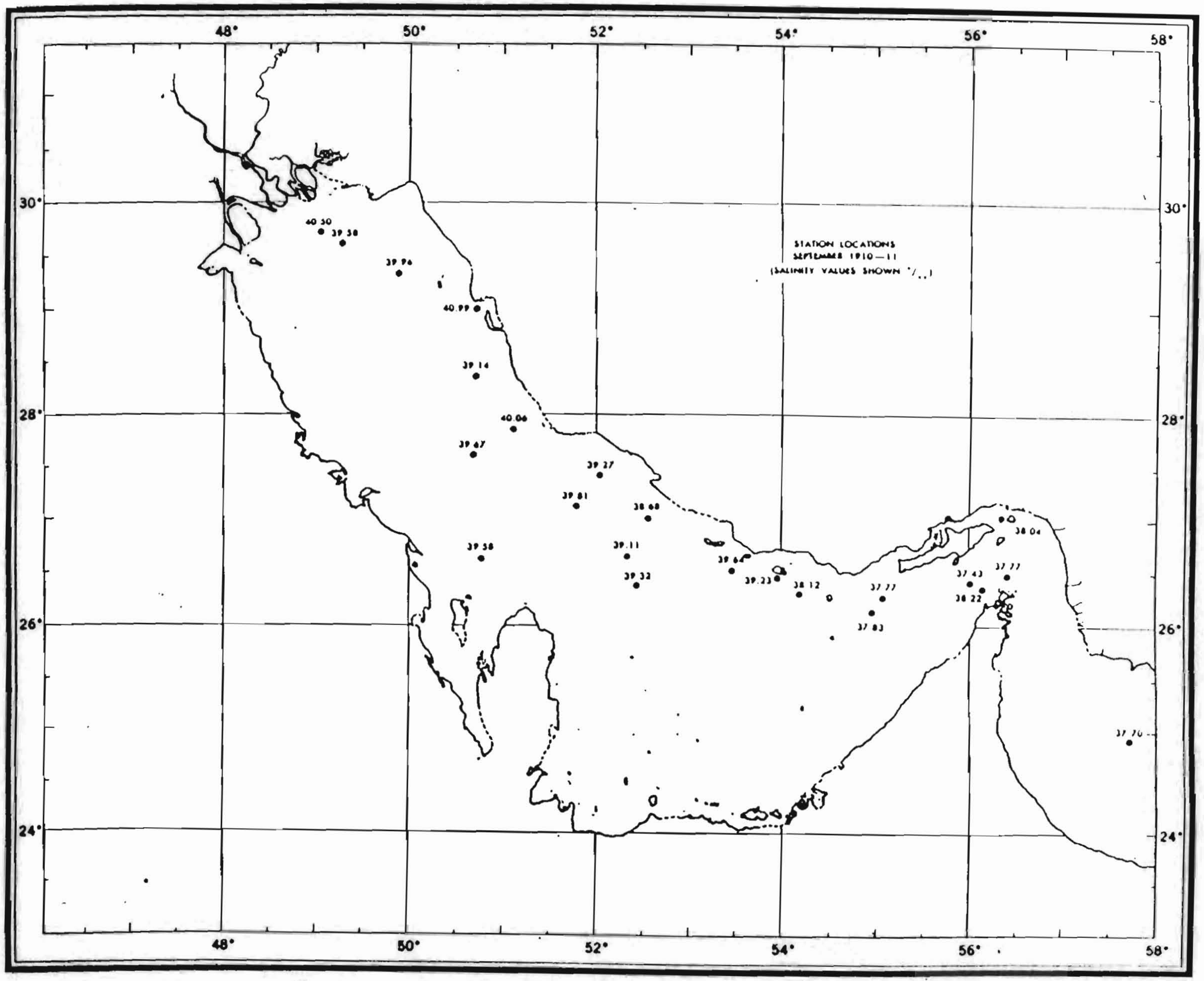


Figure . 9 Location of Surface Observations— Persian Gulf, 1910-11 SHOTT

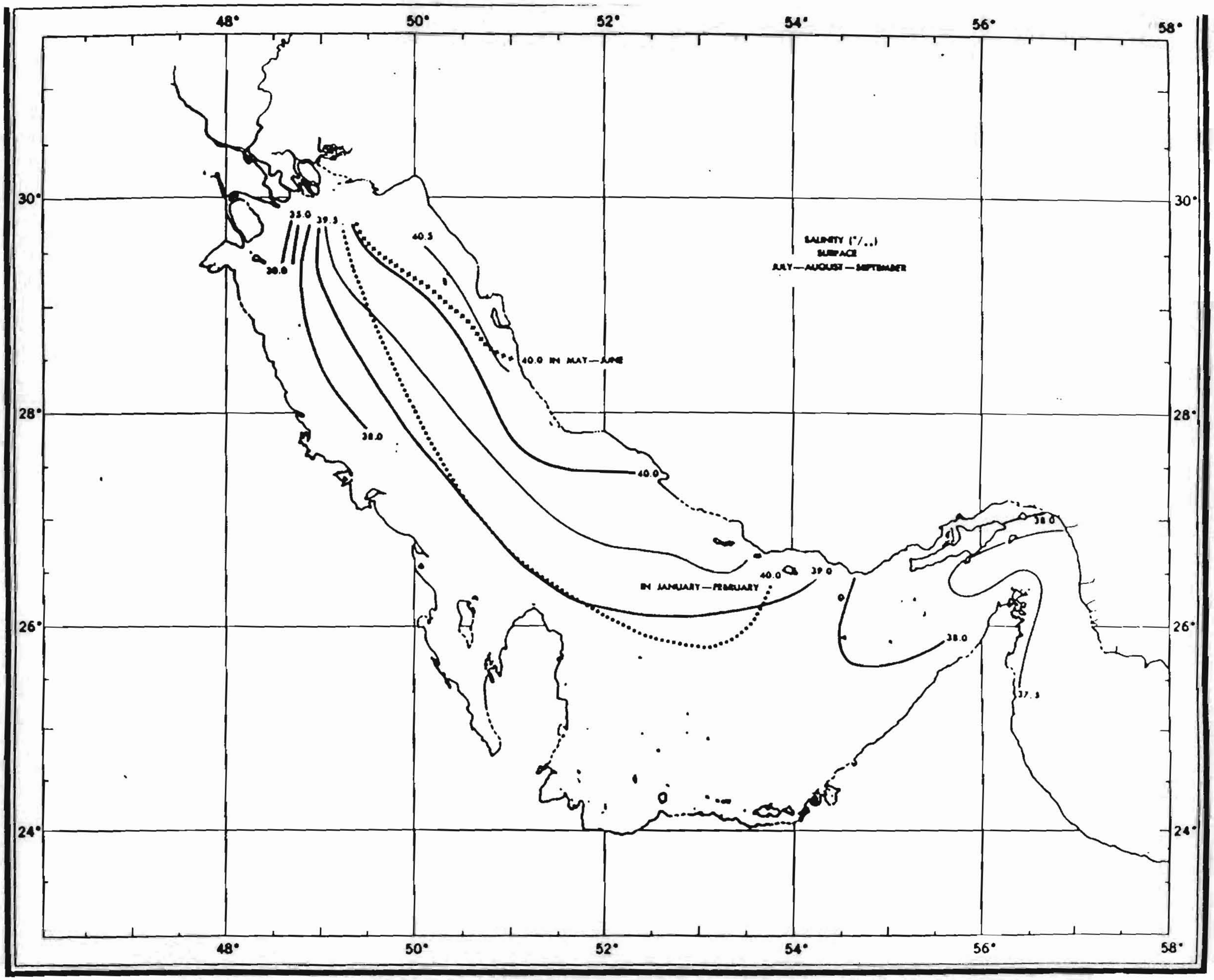


Figure 10 Persian Gulf—Salinity (°/..)—surface, Jul., Aug., Sept. SHULTZ 1914

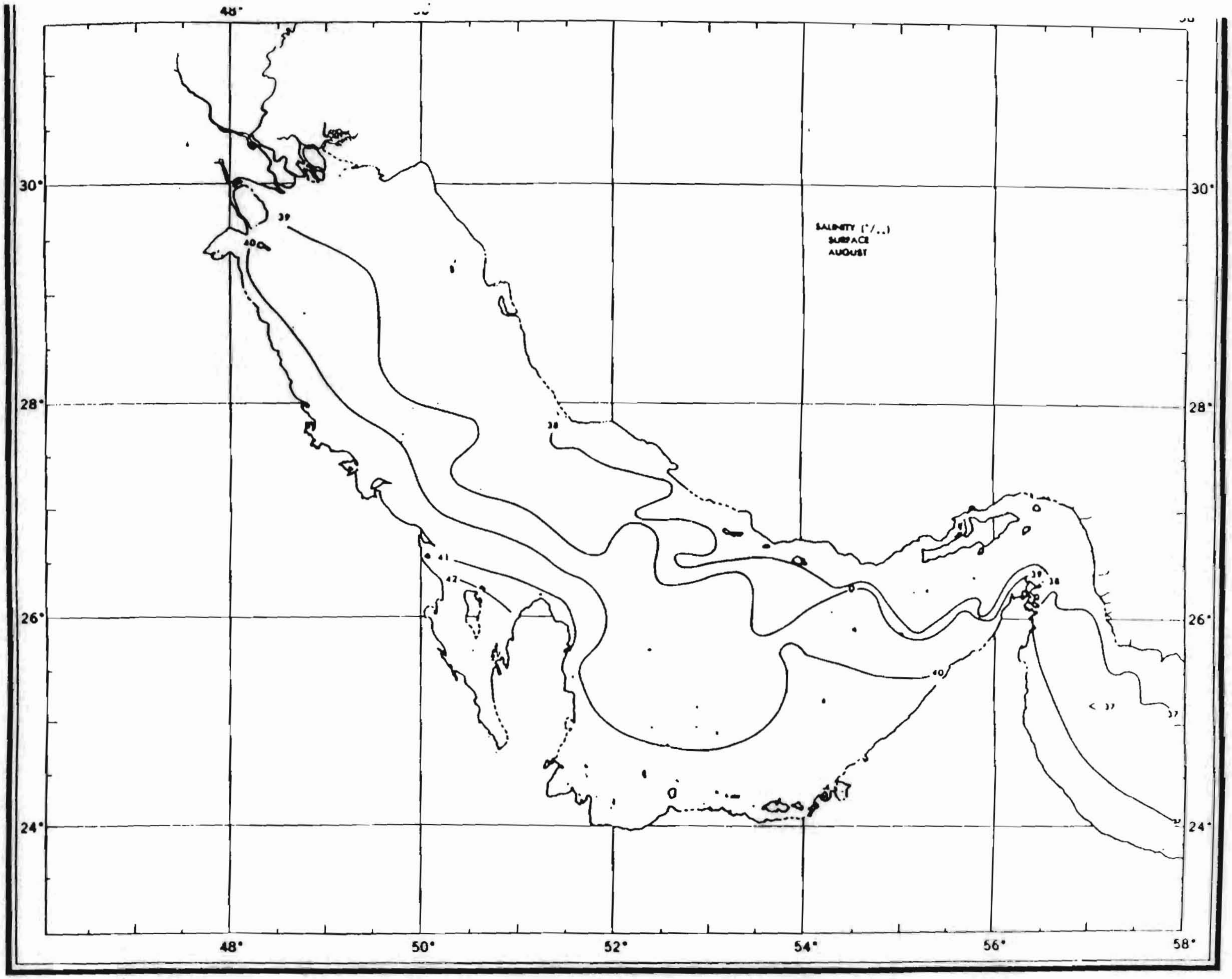


Figure 11 Persian Gulf—Salinity (°/..)—surface, Aug. EMERY 1956

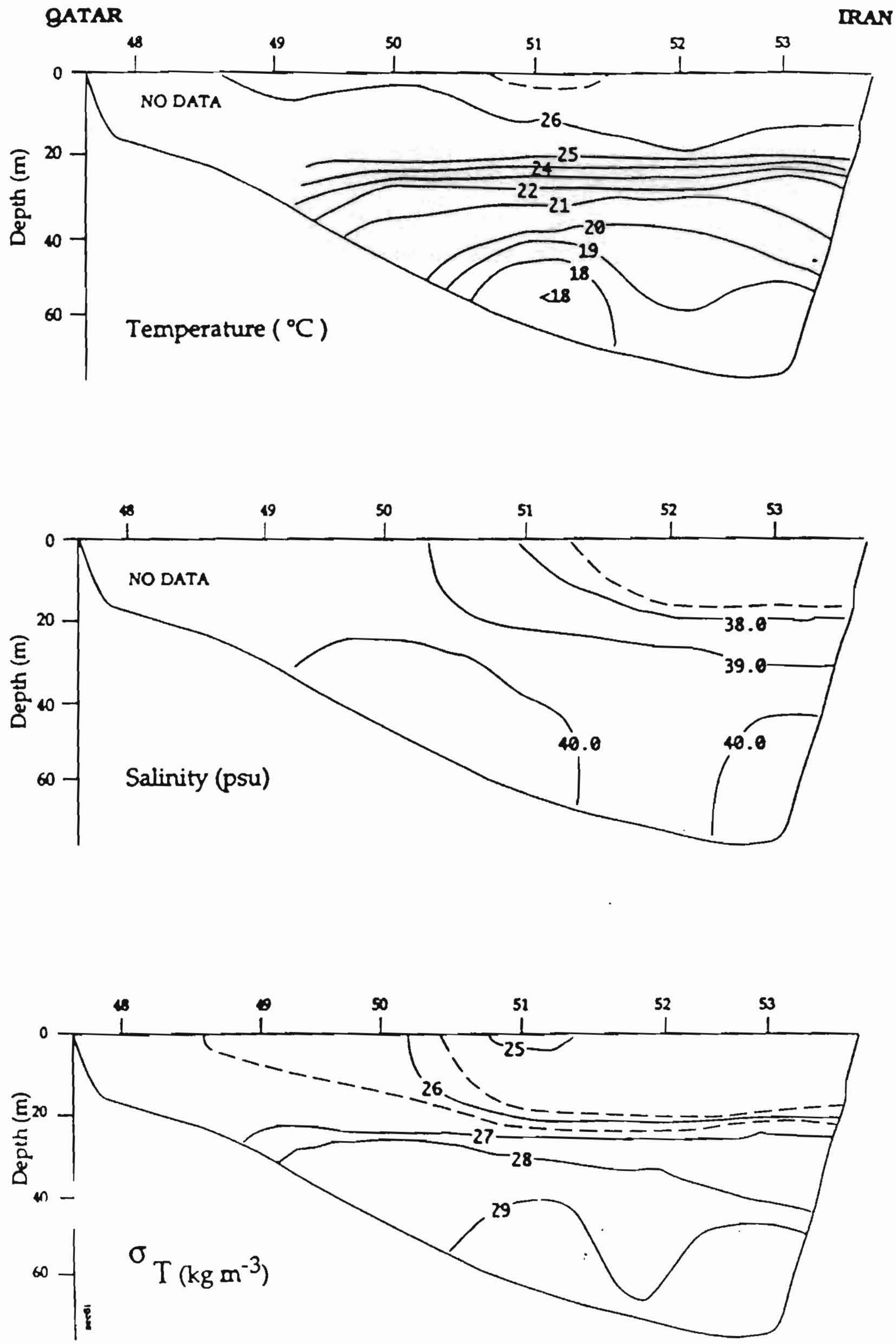


FIG. 12 CTD cross section across the central Gulf, 1993 (summer).

An international commission was established in 1901, to standardize salinity measurements, which concluded that salinity

> "is the total amount of solid materials in grams contained in one kilogram of sea water when all the carbonate has been converted to oxide, the bromide and iodine replaced by chlorine and all organic matter completely oxidized" (Neuman, 1968).

Implementing the Law of Constancy of Composition, the International Commission established the empirical relationship:

$$\text{Salinity} = 0.03 + 1.805 \times \text{chlorinity (cl) g/kg.}$$

"Normal Water" was defined as 19.4 g/kg. chlorinity and in 1937 a new international standard was established setting the chlorinity of "Normal Water" at 19.381 g/kg. The original empirical relationship was thus modified and the contemporary relationship for salinity is given as:

$$\text{Salinity} = 1.80655 \times \text{cl g/kg.}$$ (Thurman, 1993).

Thus, the salinity measurements taken by Schott and Shultz in the early twentieth century expeditions to the Arabian Gulf are very close and, therefore, valid.

As the circulation patterns of the Arabian Gulf are primarily thermohaline in nature, and the measured parameters of salinity and temperature have virtually remained unaltered over time, one can conclude that the increased salinity discharges resulting from the desalination process produce an increased salinity presence in the locality of the anthroprogenic discharge where shallow waters, tidal currents and strong winds prohibit stratification of the water mass. Desalination, therefore, produces an affect very similar to a localized, intense natural evaporation process. Increased salinities and temperatures are swiftly diluted in the prevailing coastal jet stream along the southern coast, and transported to the sinking zone, off the coast of Qatar, demonstrating no deleterious influence on the main circulating water body. Should the salinity increase be significant, then the speed of the circulating flushing currents will increase, reducing the flushing time of the complete body of water. The hypothesized global warming trend the world currently experiences, coupled with the anticipated growth in demand for fresh water utilizing the desalination process will both accelerate the fresh water extraction quota from the Gulf, eventually creating a faster thermohaline circulation rate.

Total fresh water extracted from the Arabian Gulf is the sum of the net natural evaporation and distillation product. Should the desalination product numbers compare reasonably close with the natural evaporation rate, then one may conclude that desalination plays a significant role in current circulation of the Arabian Gulf. The following calculations show that fresh water extracted through the desalination process is but 0.66 percent of the total annual natural fresh water evaporated. One may therefore conclude that desalination in the Gulf has very little influence on the natural evaporation process therein, at present rates of production.

<u>Natural Extraction of Fresh Water from the Arabian Gulf</u>

Rate of Natural Evaporation ....= 1440 mm/year

Surface Area Gulf ....= 239×10^3 km^2

Total Volume Evaporated........................ = 239×10^9 m^2 x1.44m/year

= 344.16×10^9 m^3/year

Total World Desalination Capacity........... = 15582000 m^3/d

of which Saudi Arabia has 24.4%, but 63% of this capacity is extracted from the Persian Gulf (El-Dessouky, 1994, and Ministry of Agriculture and Water, Riyadh, Saudi Arabia, 1984)

Gulf Coast States Extraction of Fresh Water from the Arabian Gulf

Saudi Arabia	15.37%
Kuwait	9.1%
UAE	10.6%
Bahrain & Qatar	5.0%
	40.07% of total world desalination capacity

Fresh water extraction from Gulf ....= 365 x 15, 582, 000 m^3/d x 0.4007

per year = 2.275 x 10^9 m^3/year

which is 0.66% of the total Natural Evaporation Rate for the year

The Southern Arabian Gulf and the Limiting Factor of Salinity

It is observed that the industrial zones of Saudi Arabia, Bahrain, Qatar, and The U.A.E. correspond directly with the littoral zones of naturally occurring high salinity. As noted previously, these zones are shallow and subjected to high rates of evaporation. Fig. 6 (p. 37) shows the influence of the strong coastal jet originating at the head of the Gulf, but deflected away from the coast by the Qatar Peninsula and the coral reefs connecting Qatar and Bahrain. This peninsula also results in the separation of the shallow coast of the western U.A.E. from the predominant gyre, thus creating an area of relative stagnation. In both summer and winter, most evaporation occurs in the main two embayments of the south, to the east and west of Qatar, where depths are less than 10 m. for thousands of km^2 (Sheppard, 1994). Here, the flow is strongly dominated by the wind, which generates an Ekman flow in an easterly direction, and because of the shallow depths, the bottom flow is dragged in the same direction (Lardner, et al, 1994).

Any disruptive influence of desalination or industrial effluents on the ecology of the Gulf will initially manifest itself here in the shallow and vulnerable embayments of the South. The Gulf of Salwah is particularly vulnerable where average salinities of 56.5 g/kg. naturally occur. This Gulf is a semi-enclosed embayment surrounded by the coastlines of Saudi Arabia, Qatar, and Bahrain (Fig. 13). Reefs stretching from Qatar to Bahrain Island restrict water circulation, increase residence time of the entrapped waters and high evaporation produces elevated salinities ranging up to 60 g/kg. in open water and above 70 g/kg. in embayments, therein (Coles, and McCain, 1990).

The Gulf of Salwah may be viewed as a smaller, but more extreme, model of the Arabian Gulf as a whole, as the formation of hypersaline water therein may be one of the most important sources of the salinity related density gradient to drive circulation in the Arabian Gulf (Johns, Coles, and Abazed, 1990). Density stratification in the Western Gulf occurs only near the entrance to the Gulf of Salwah, where the northward movement of highly saline Gulf of Salwah bottom water intrudes under less saline Western Gulf water forming a density structure of a typical reverse estuary, a situation found also at the Staits of Hormuz. The high salinity surface waters and high evaporation rates in the Gulf of Salwah induce a strong pycnocline in these relatively stagnant, entrapped waters, producing a northward movement of high saline bottom water. As in the case of the main Gulf circulating gyre, an increase in the rate of salinity addition will produce a stronger bottom current in this region also. Therefore, the physical consequences of desalination effluent are effectively neutralized by nature's compensating pressure gradient, flow inducing, circulating mechanisms.

However, the biological consequences are more debilitating. Research compiled in the early 1970s revealed salinity to be the most important and pervasive influence on benthic organisms in the Western Arabian Gulf (Clarke, and Keij, 1973). Here, in all

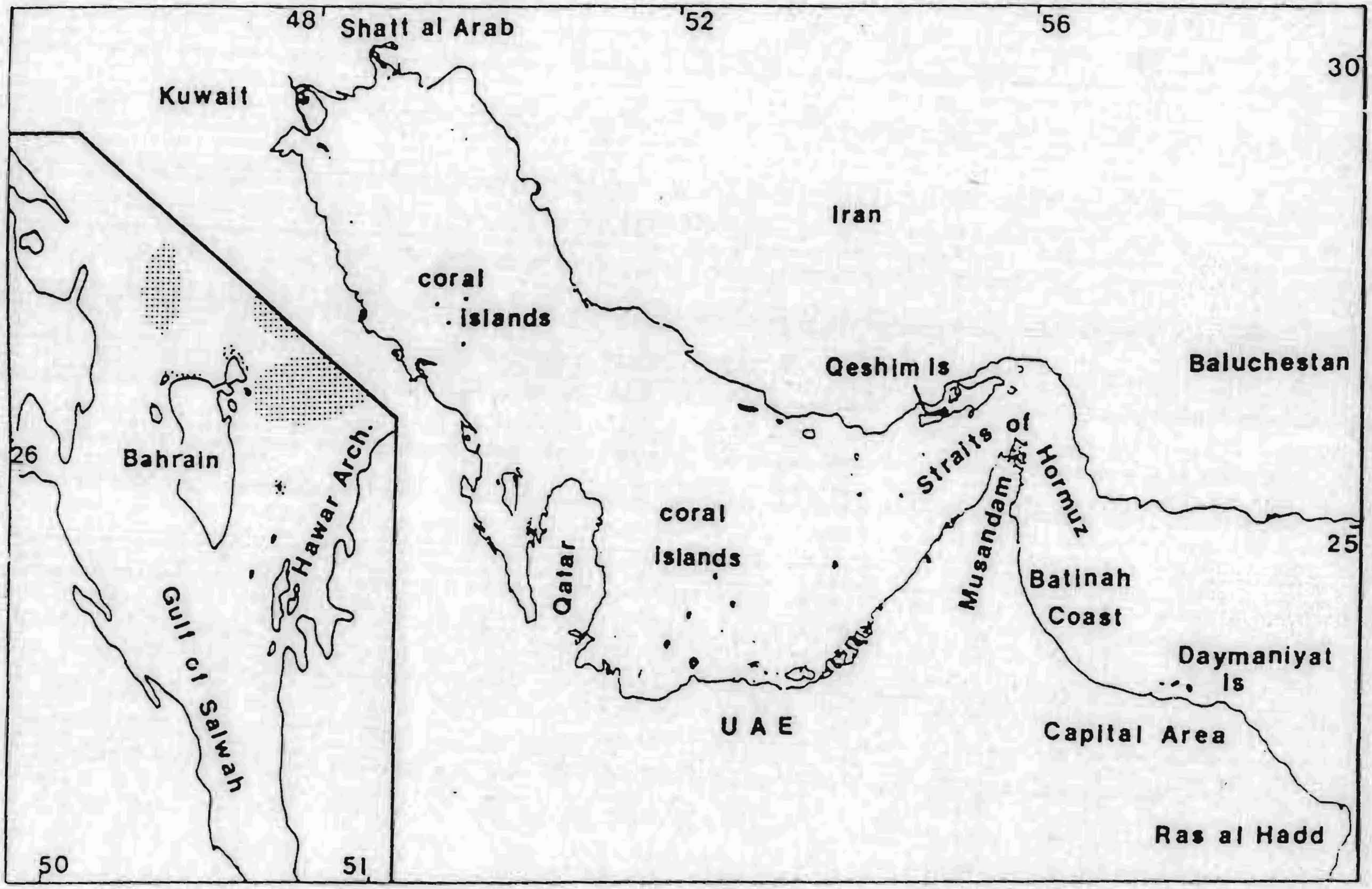


Fig. 13 The Gulf (with Gulf of Salwah, inset). Northern coral islands are true coral cays, southern group off UAE are mostly elevated limestone platforms, many supporting coral communities but few with true reefs. Shaded area in Gulf of Salwah (inset) depicts reefs which restrict water flow (from Sheppard & Sheppard, 1991).

cases, except for biomass in Sand/Salt, the relationship of salinity with the dependent variable is negative, indicating that increasing salinity restricted the numbers of species individuals, and species diversity in seagrass beds where benthic organisms are generally more abundant. Restriction of benthic organisms by increased salinity has been qualitatively observed in the Gulf at salinities above 45 g/kg., in the Gulf of Salwah and in the Abu Dhabi, U.A.E., barrier island complex. Hard and soft corals, melobesoid and other red algae, articulated brachiopods and many species of surface living mollusks and echinoderms are conspicuously absent from the Gulf of Salwah (Clarke, and Keij, 1973). Echinoids, phoronids, penacids, carideans and halacarideans were totally absent from stations where salinities exceeded 45 g/kg. and hydroids, gastropods, pelecypods, copepods, garmarideans, mysids, astracods, stomaropods, deeapods and holothurians had 50 percent or more of their total species absent from these stations (Coles, and McCain, 1990). These conclusions verify the stressful effect elevated salinity has on even the relatively hardy marine species that occur in the Gulf. The biota is, in many cases, living at the extreme limits of its environmental tolerance which is important in any consideration of the effects of additional stresses imposed by man (Sheppard, 1994). What of the affects of high salinity on the coral reefs of these regions? We know from studies conducted by Cary (1918) and Bayer (1961), that coral reefs are best developed where the surface salinity averages about 36 g/kg. Temperatures from 34°C to 38.2°C caused the mortality of most gorgonians. In general, the Gulf reefs can be regarded as marginal coral reefs, a phrase which implies a more or less precarious existence and one which is near to their ability to survive at all (Price, Sheppard, and Roberts, 1994).

What has been verified for benthic organisms and coral assemblages is likewise true for mangroves, their associated flora, and the ichthyofauna of the Arabian Gulf. Only a single eurythermal and euryhaline species of mangrove, Avicennia marina, occurs naturally due to the extremes of water and atmospheric temperature fluctuations and salinities in the Gulf. Avicennia reaches 6 m. tall in areas outside the Gulf proper, whereas in the Gulf, trees are poorly developed and often stunted (1-2 m.), particularly along western shores (Price, et al, 1994). Likewise, the ichthyofauna of the Gulf is less diverse than that of the adjacent Indian Ocean. Some species live as close as 1°C to their thermal tolerance limits (Price, et al, 1994). Increasing salt concentrations prevent the growth of an increasing proportion of marine bacteria. Sodium Chloride salt ($NaCl$) is well known as an agent against bacterial growth -- this is the basis for its past widespread use as a preservative against bacterial spoilage. As saline conditions gravitate towards extreme conditions in the Southern Gulf, the survival of a reduced variety of biotic flora and fauna is evident as hypersalinity severely restricts the ability of organisms to survive (Nissenbaum, 1980).

As demonstrated, the natural flushing currents of the Gulf amply accommodate the efficient dilution of excess salinity and high temperature effluent in the macro-ecological setting. What of the biological effects in way of the desalination plant discharge pipeline? A recent investigation of the biological effects of such a plant's discharge was completed by the Federal Water Quality Administration in 1970, at Key West, Florida (Clarke, Jay, and Rosenthal, 1970). Sea water at 40 g/kg. and a temperature of 25.6°C was pumped from the littoral Caribbean to commence the desalination process. Effluent was discharged at a rate of 26,000 m^3/day, at a salinity of 55 g/kg. and a temperature of 37°C to complete the process - - salinity characteristics similar to those of the Arabian Gulf. It is reported therein that high salinity is the controlling density property of the effluent, as the greater portion of the plume sinks after it leaves the discharge pipe. The dominance of salinity is indicated by the presence of thermal inversions, the higher temperature of the discharge plume stratified below the lower temperature of the surrounding ocean. As the plume moves away from the discharge point, it becomes more dense through the loss of heat and gradually sinks. Therefore, it is the benthic organisms that are more drastically affected. Results of the Key West investigation showed that coral up to 12 meters from the discharge pipe were either dead or damaged; growths of brown, red and green algae were totally absent ; and the black tunicote (Ascidia Nigra), gastropods and cheilostomatid bryozoans were severely stunted in their development. Other species such as barnacles and stone crabs appear to thrive in way of the discharge plume.

As the study did not isolate the various anthroprogenic agents in the discharge plume, the biological consequences of each physical constituent could not be verified. Elevated temperature, hypersalinity, metal ion concentrations and chemical discharges during descaling operations may each be involved to varying degrees. However, it was reported that the release of extremely acidic water (pH 2.0) during descaling operations was the most probable biological destabilizing influence. In the US, the Clean Water Act of 1972 (33 USC 466 et seq), prohibits all such vitriolic discharges; classed as hazardous waste, the law mandates neutralizing treatments, at additional expense, prior to discharge.

From this research one may conclude that desalination effluent does adversely affect the biological balance in the vacinity of its anthroprogenic discharge. In the Arabian Gulf, as one approaches land from a seaward direction, the increasing salinity and range of diurnal temperature change extracts an increasing toll on the biodiversity of the littoral sea. Any influence that exasperates these conditions can accelerate this reduction and, as shown from the Key West Investigation, desalination does have a localized deleterious influence.

CHAPTER VI

AN EVALUATION OF ECONOMIC VIABILITY

European Fresh Water Supply Costs

Rotterdam

Industrial water charges for large volumes of potable water from Rotterdam's Municipal Waterworks are approximately \$0.90 per m^3. Port loading charges, including anticipated storage and pumping charges, are \$0.75 per m^3 (Wielenga, 1985). As simultaneous tanker discharge and fresh water loading is considered, no associated costs for delays are included. The onboard cost at Rotterdam is \$1.65 per m^3.

Fos/ Marseilles

Potable fresh water at this port is F8/m^3. Port wharfage charges for bulk liquid cargoes are F1.53/m^3, which gives a total on board water cost of F9.53/m^3 or \$1.66/m^3 (Masson, 1994).

To facilitate the many international monetary conversions necessary in this study and to provide a common US dollar base for comparison, the currency trading rates of Mar. 29,1994 are reproduced in Fig. 14.

CURRENCY TRADING

EXCHANGE RATES

Tuesday, March 29, 1994

The New York foreign exchange selling rates below apply to trading among banks in amounts of $1 million and more, as quoted at 3 p.m. Eastern time by Bankers Trust Co., Dow Jones Telerate Inc. and other sources. Retail transactions provide fewer units of foreign currency per dollar.

	U.S. $ equiv.		Currency per U.S. $	
Country	Tues.	Mon.	Tues.	Mon.
Argentina (Peso)	1.01	1.01	.99	.99
Australia (Dollar)	.7028	.7115	1.4229	1.4055
Austria (Schilling)	.08476	.08492	11.80	11.78
Bahrain (Dinar)	2.6522	2.6522	.3771	.3771
Belgium (Franc)	.02895	.02900	34.54	34.49
Brazil (Cruzeiro real)	.0011189	.0011401	893.75	877.15
Britain (Pound)	1.4825	1.4962	.6745	.6684
30-Day Forward	1.4807	1.4942	.6754	.6693
90-Day Forward	1.4772	1.4907	.6770	.6708
180-Day Forward	1.4737	1.4874	.6786	.6723
Canada (Dollar)	.7270	.7275	1.3755	1.3746
30-Day Forward	.7262	.7268	1.3770	1.3759
90-Day Forward	.7242	.7250	1.3809	1.3793
180-Day Forward	.7211	.7228	1.3868	1.3835
Czech. Rep. (Koruna)				
Commercial rate	.0341332	.0340959	29.2970	29.3290
Chile (Peso)	.002406	.002406	415.65	415.65
China (Renminbi)	.114929	.114929	8.7010	8.7010
Colombia (Peso)	.001218	.001218	821.15	821.15
Denmark (Krone)	.1514	.1518	6.6070	6.5861
Ecuador (Sucre)				
Floating rate	.000478	.000478	2091.00	2091.00
Finland (Markka)	.18073	.18077	5.5331	5.5318
France (Franc)	.17440	.17483	5.7340	5.7200
30-Day Forward	.17402	.17444	5.7464	5.7325
90-Day Forward	.17335	.17376	5.7688	5.7550
180-Day Forward	.17265	.17309	5.7920	5.7775
Germany (Mark)	.5964	.5976	1.6767	1.6735
30-Day Forward	.5953	.5965	1.6797	1.6765
90-Day Forward	.5936	.5948	1.6847	1.6813
180-Day Forward	.5920	.5931	1.6893	1.6860
Greece (Drachma)	.004048	.004068	247.05	245.80
Hong Kong (Dollar)	.12945	.12946	7.7250	7.7245
Hungary (Forint)	.0097714	.0097618	102.3400	102.4400
India (Rupee)	.03212	.03212	31.13	31.13
Indonesia (Rupiah)	.0004651	.0004651	2150.03	2150.03
Ireland (Punt)	1.4365	1.4416	.6961	.6937
Israel (Shekel)	.3359	.3359	2.9770	2.9770
Italy (Lira)	.0006094	.0006121	1641.09	1633.77

	U.S. $ equiv.		Currency per U.S. $	
Country	Tues.	Mon.	Tues.	Mo
30-Day Forward	.009664	.009614	103.48	104.
90-Day Forward	.009693	.009644	103.17	103.
180-Day Forward	.009747	.009696	102.60	103.
Jordan (Dinar)	1.4599	1.4599	.6850	.68
Kuwait (Dinar)	3.3639	3.3639	.2973	.29
Lebanon (Pound)	.000590	.000590	1695.50	1695.
Malaysia (Ringgit)	.3717	.3718	2.6900	2.68
Malta (Lira)	2.6042	2.6042	.3840	.38
Mexico (Peso)				
Floating rate	.2978229	.2978584	3.3577	3.35
Netherland (Guilder)	.5304	.5313	1.8854	1.88
New Zealand (Dollar)	.5648	.5691	1.7705	1.75
Norway (Krone)	.1369	.1373	7.3034	7.28
Pakistan (Rupee)	.0329	.0329	30.40	30.
Peru (New Sol)	.4718	.4718	2.12	2.
Philippines (Peso)	.03683	.03683	27.15	27.
Poland (Zloty)	.00004538	.00004557	22037.00	21946.
Portugal (Escudo)	.005758	.005784	173.67	172.
Saudi Arabia (Riyal)	.26667	.26667	3.7500	3.75
Singapore (Dollar)	.6374	.6313	1.5689	1.58
Slovak Rep. (Koruna)	.0307409	.0305344	32.5300	32.75
South Africa (Rand)				
Commercial rate	.2900	.2900	3.4485	3.44
Financial rate	.2099	.2109	4.7650	4.74
South Korea (Won)	.0012364	.0012355	808.80	809.
Spain (Peseta)	.007269	.007277	137.57	137.4
Sweden (Krona)	.1265	.1267	7.9082	7.893
Switzerland (Franc)	.7013	.7032	1.4260	1.422
30-Day Forward	.7009	.7028	1.4268	1.422
90-Day Forward	.7007	.7027	1.4271	1.423
180-Day Forward	.7016	.7035	1.4254	1.421
Taiwan (Dollar)	.037874	.037874	26.40	26.4
Thailand (Baht)	.03960	.03960	25.25	25.2
Turkey (Lira)	.0000455	.0000457	21980.99	21891.0
United Arab (Dirham)	.2723	.2723	3.6725	3.672
Uruguay (New Peso)				
Financial	.218007	.218007	4.59	4.5
Venezuela (Bolivar)				
Floating rate	.00874	.00874	114.40	114.4
SDR	1.41232	1.40702	.70805	.7107
ECU	1.14920	1.15490	....	..

Special Drawing Rights (SDR) are based on exchange rate for the U.S., German, British, French and Japanese curren cies. Source: International Monetary Fund.

European Currency Unit (ECU) is based on a basket o

FIG.14 CURRENCY TRADING 29 MARCH 1994 (WALL STREET JOURNAL)

To calculate the total fresh water ballast capacity on the Western European to Arabian Gulf shipping route, and thus the total water export potential, the following calculations are necessary:

1992 Imported Crude Oil	Rotterdam........................... 102.3	m Tonnes
1992 Imported Crude Oil	Fos/Marseilles.......................65.0	m Tonnes
1992 Total	Both Ports...........................167.3	m Tonnes

Total Ballast Water (1/3 Cargo Capacity)............................55.77 m Tonnes

84% of Imported Crude was by VLCC
VLCC Correction Factor ....46.844 m Tonnes
(Champness, and Jenkins, 1985)

Total Fresh Water Capacity...46.844 m Tonnes

If total ship cargo volumes are utilized in the export of fresh water and the resultant oil contaminated water is acceptable to Arabian consumers, the total water export volumes from Western Europe and all major world oil importers are as follows:

1992 Total Oil Imported to Western Europe.........................194.2 m Tonnes
At 3,878,000 b/d (<u>International Petroleum Encyclopedia</u>, 1993), (Fig.15).

1992 Oil Exports from Middle East to Major World Oil Consumers and Potential Suppliers of Fresh Water (Fig.15):

Japan...3,298,000 b/d

SE. Asia...3,357,000 b/d

Europe...3,878,000 b/d

USA...1,958,000 b/d

World Total...12,491,000 b/d

= 625.5 m Tonnes

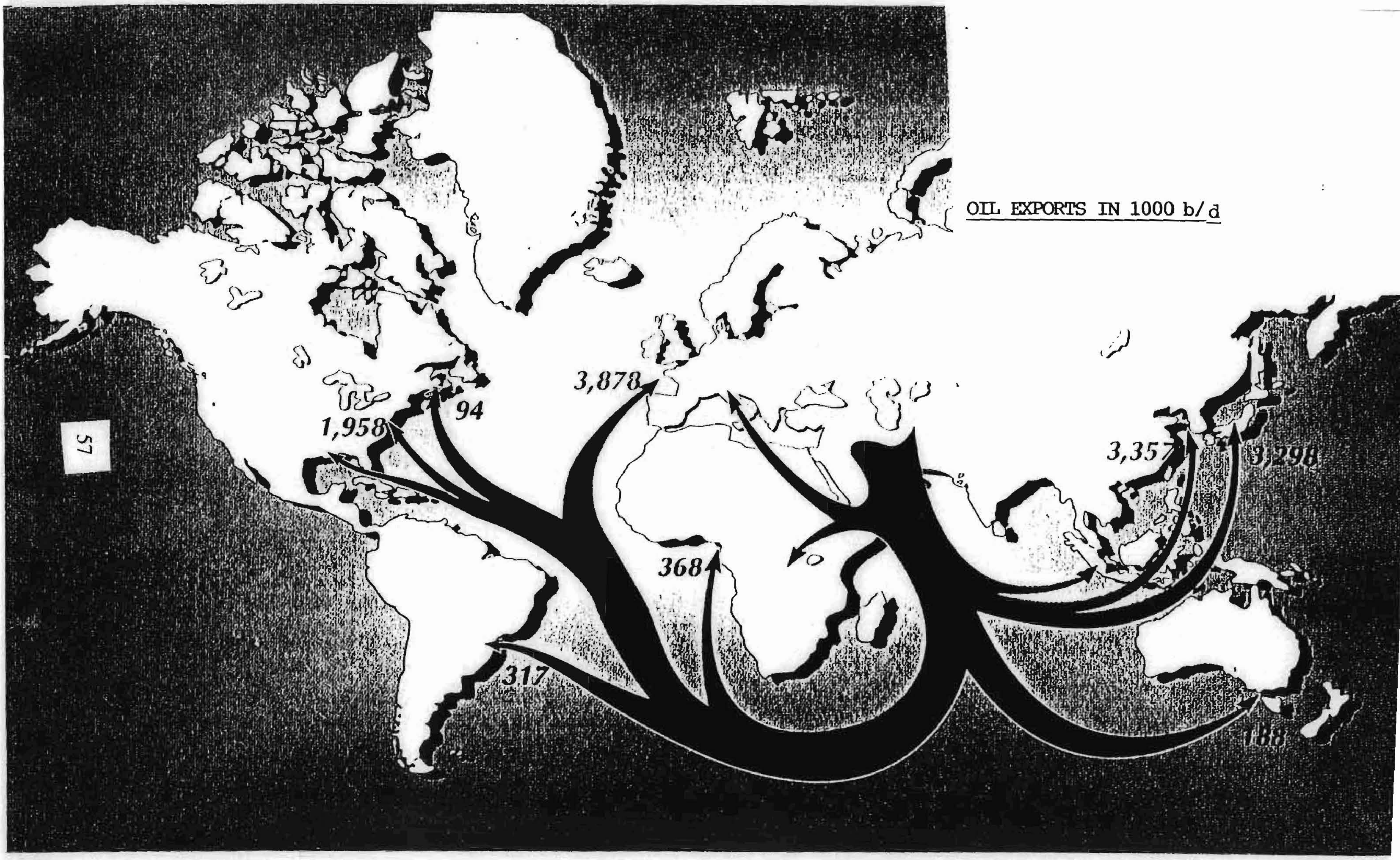


FIG.15 CRUDE OIL EXPORTS FROM THE MIDDLE EAST (INTERNATIONAL PETROLEUM ENCYCLOPEDIA 1993)

The production of fresh water by desalination in Arabia necessary to satisfy regional demand equals the total fresh water extracted from the Gulf for this purpose.

Total Desalinated Water Extracted from Gulf, (p.48) .... 2.275×10^9 Tonnes/year.

A knowledge of VLCC fresh water supply capabilities and actual Arabian demand facilitates the rudimentary calculations necessary to conclude the following:

a) Backhaul capacity from Rotterdam and Fos/Marseilles in one year, would provide sufficient fresh water to satisfy Arabian Gulf demand for 7.5 days.

b) If most major European oil import centers had fresh water exporting facilities, Arabian Gulf demand would be satisfied for nine days.

c) If the world's most significant oil importers, all provided fresh water exporting facilities, Arabian demand would be satisfied for 28 days, or approximately .. one month.

d) If the world's most significant oil importers exported fresh water loaded to ship capacity, Arabian demand would be satisfied for three months.

Should some of the smaller emirates of the Middle East consider fresh water backhaul, the following calculations demonstrate the limit of their prospective involvement:

e) Total World Desalination Capacity.................... 15,582,000 Tonnes/day

Kuwait @ 9.1% produces .... 1.42 m T/day (517 mT/year)

Qatar @ 3% produces.............................0.47 mT/day (170.6 mT/year)

Bahrain @ 2% produces .... 0.31 mT/day (113.75 mT/year)

Fresh Water from Rotterdam and Fos/Marseilles could satisfy:

Kuwaiti demand for....... 1 month

Qatari demand for over...3 months

Bahraini demand for........ 5 months

Costs of Arabian Desalination

Mr. A. Akkad (Saudi Arabia), King Fahd University of Petroleum and Resources stated:

> "It has been estimated that the cost of production per cubic meter of desalinated water in this region (Middle East) is in the range of SR 4-11" ($1.06 - $2.93/m3) (Akkad, 1989).

Mr. Al-Bakeri and Mr. Elhares (UAE) stated:

> "Monthly operations report of the Western E. District directorate of the Power and Desalination plants from January 1992, the water gross production cost (including fuel, spare parts, labor and depreciation) for the year 1991 was estimated to be approximately 20 Dhs/k Gal. ($1.22/$m^3$)" (Al - Bakeri, and Elhares, 1993).

Mr. Dabbagh and Mr. Al - Saqabi (Kuwait) recently stated:

> "The 1983/1984 average cost of desalinated water is $1.6/$m^3$, not including distribution costs." (Dabbagh, and Al - Saqabi, 1989).

Mr. O. J. Morin (US), in a 1993 comprehensive breakdown of related desalination costs for a 38,000 m^3/day MSF plant, with a performance ratio of 8, quoted the total cost of water at $/kGal 7.34 ($1.94/m^3) (Morin, 1993). As most desalination plants in the Middle East are operated as co-generation plants producing electricity and desalinated water, the associated fuel costs for desalination are projected as 50 percent those of a single purpose desalination unit (Ali El-Saie, 1993). Modifying Mr. Morin's breakdown to reflect a 50 percent fuel savings, more in line with conventional Middle East operations, the modified cost of desalinated water is $1.41/$m^3$.

The above presentation of associated costs in four separate water producing countries from four individual and unrelated authors portrays a water cost predominantly in the $1 -2/$m^3$ range. This contrasts significantly with the pejorative desalination price of $4.50 - 8.00/$m^3$ as quoted by Mr. Wielenga, deputy General Manager, Municipal

Waterworks of Rotterdam (Wielenga, 1985). Mr. Meyer, then chairman of the International Association of Independent Tanker Owners (Intertanko), stated the cost range for desalinated water as \$ 3 - 6/m^3 (Meyer, 1985). The esoteric nature of both the latter author's figures begs elucidation as these anomalous quotations may well foster accusations of sophistry.

CHAPTER VII

CONCLUSIONS

The Viability of the Fresh Water Backhaul Enterprise

The cost factors associated with the purchase of fresh water at European ports and those associated with the production of desalinated water in the Middle East do not verify the commercial viability of the backhaul enterprise. As presented, maritime transportation costs were not included in the procurement costs of European fresh water. It is unrealistic to expect the VLCC owner to transport cargo free, albeit, there are associated advantages for him to do so. Port infrastructure and reception facilities to land and perhaps store the imported fresh water would further add to the capital costs associated with the backhaul enterprise. Both these cost essentials would further erode the competitiveness of the European export of fresh water by VLCC. Thus, the utilization of VLCCs to backhaul fresh water to the Middle East, as hypothesized, is deemed economically uncompetitive with the autonomous desalination process already established in the Arabian Gulf.

An additional limiting factor is the discrepancy in fresh water volumes of potential VLCC supply and Middle East demand. The fresh water capacity utilizing present European VLCC routes is totally inadequate to meet current Arabic fresh water demand, even should fully loaded VLCCs be considered, not just ballast space backhaul.

Fresh water demand is growing rapidly in the Middle East, whereas total European oil imports from the Middle East have declined in the recent past (Evans, 1991). Hence, the long-term sustainability of fresh water supplies utilizing this supply vector, should current oil trading trends continue, is questionable and not conducive to its implementation.

On an individual basis, the small populations of Qatar and Bahrain may perceive some merit in the proposal, ostensibly, in a supplementary manner. However, the probability of a significant percentage of returning VLCCs maintaining a regular oil loading berth at or close to both countries is very remote, given the prevailing charter market. Hence, if fresh water backhaul supplies were initiated, it could only be on an ad-hoc basis.

The backhaul enterprise may offer some limited advantage to Kuwait and Saudi Arabia. Both countries own and operate large tanker companies. The significant potential savings in VLCC operations and maintenance makes the enterprise attractive, again, in an entirely supplemental capacity to existing sources of fresh water. From the volumes of brackish water used by Saudi Arabia for agricultural purposes, a blend of pure water from Europe and the indigenous brackish supplies may provide large volumes of potable water suitable for human consumption. This proposal deserves further investigation. Thus, one may conclude from these considerations that the VLCC backhaul of fresh water from Europe is not a commercially viable proposition on the whole, providing limited and marginal benefits only in individual and isolated circumstances, at best.

Sustainable Development and the Backhaul Enterprise

Contrary to popular belief, the desalination process, as described herein, does not appear destructive and unsustainable to the Arabian Gulf ecosystem. Nature's oceanic flushing mechanisms are simply augmented by the anthroprogenic discharge of that sea water constituent, salt, which fuels the flushing process in the first place. The increased temperature of discharge waters is rapidly sublimated to surrounding ocean levels by the shear mass differential of these waters and those of the Arabian Gulf itself. The biological consequences of the anthroprogenic discharge are manifest in an area approximately 12 meters from the discharge outlet. The dilution process is, therefore, rapid in the littoral ocean, but these consequences can be simply and inexpensively eliminated by adequate dilution of discharge waters prior to discharge. A prohibition on the dumping of the vitriolic descaling residue should unequivocally be imposed, undoubtedly the only unsustainable activity of the desalination process. A noticeable theme in the desalination literature, emanating from this region, is the complete lack of reference to the anthroprogenic biological affects of the desalination process in the littoral seas. From the Key West Report, it is evident that a more comprehensive and detailed analysis of such discharges is required.

The conservation of energy to be realized in the postponement of planned desalination capacity increases, should the fresh water backhaul enterprise materialize, is insignificant given the huge disparity in the potential supply therefrom and Arabic demand. Furthermore, conservation of energy may not be high on the agenda of these oil soaked nations although, in their case, a barrel saved is, indeed, a barrel sold.

The VLCC Owner and Fresh Water Cargo

Perhaps the biggest winner, should the instigation of the fresh water backhaul enterprise occur, is the tanker owner. If a reasonable cost of carriage is implemented, the additional savings in operations and maintenance of VLCCs, in conventional maritime practices, are auspicious. However, should the recent innovation and predicted expectations of the Zinc Silicate maritime paint prove sustainable, the deleterious affects of salt water within ballast tanks and double hulls may be significantly reduced. This innovation, coupled with the introduction of an acoustic defect detection system to almost eliminate entirely the antediluvian visual survey techniques of these spaces, would abate many of the proposed benefits associated with an exclusive fresh water ballast medium.

It is further proposed that VLCC operators, in trading with the Gulf Nations, could successfully petition for exemption from the Non-Indigenous Species Act requirements on the grounds that the hypersalinity of the Gulf will eliminate the possibility of most low salinity, ballast water organisms of surviving in such waters. As previously stated, many of the acclimatized species of flora and fauna of the Arabian Gulf are themselves on the verge of extinction, thus providing little chance for the survival of newly introduced low salinity or stenohaline species. Such an exemption would alleviate the requirement of en route deballasting and reballasting as mandated in the forthcoming law. It should be noted that the zebra mussel cannot survive in waters of salinity greater than 10 - 12 g/kg (Carlton, 1994). Therefore, from an Arabic view point, there is little economic or social incentive to consider fresh water transportation by VLCC.

The strategic value of fresh water supplies of any nation cannot be underestimated. However, the sensitivity associated with Middle Eastern fresh water supplies has reached esoteric proportions. Given the large economic resources devoted to self-sufficiency in food and water, and the current extremely low crude oil prices, one wonders if such practices are defensive strategies designed to cushion reaction from a future Western oil embargo? Of the nine Arabian Gulf nations and the three independent regional fresh water experts contacted in the course of this research, this author received not one reply. One of the experts himself wrote:

> "Unfortunately, some institutions responsible for desalination plants are reluctant to give accurate and comprehensive data related to operation and maintenance of (desalination) equipment. Surely, this does not help in evaluating the situation and could delay development in this field" (Ali El - Saie, 1993).

The frustration, clearly evident in these remarks, becomes clearer with the realization that as the issue of water resources management and allocation has crept onto the strategic agenda in the Middle East, so water related data have become politically sensitive. As a result, no figures for water availability or consumption are undisputed or ultimately verifiable to a satisfactory extent (Beschorner, 1992). The figures obtained for this research, in a circumlocutory investigation of the literature relating to the engineering science of desalination in the Middle East, are perhaps the most reliable.

In the plutocracies of the Middle East, as the intricate web of mistrust and self-interest is woven into national policy, fresh water allocation has greater potential as a "casus belli" than as an excellent focus of interstate cooperation. A cost-effective solution to fresh water supply in the Middle East will remain elusive as long as this web entangles political relations among brother Muslim nations of the region. It is evident from this research, that the VLCC has no significant role to play in the commercial unification of Western fresh water supply and Islamic demand, thereby mandating an interregional solution for tenable fresh water supplies or maintaining the status quo of costly self-sufficiency.

The hypothesized utilization of VLCCs to backhaul fresh water to the Middle East is impalpable and cannot be considered as a viable, sustainable, or commercially sound alternative to satisfying fresh water demand in the Arabian Gulf. As evinced, some small advantages may be gained by some of the principle players involved, but overall, the hypothesis is soundly rejected.

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