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Abstract:

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Technically FWBH is feasible as the technical modifications and new infrastructure to be developed for FWBH can be integrated with the present oil tanker and trade infrastructure.

Costs are estimated both on a general and scenario specific level. It is found that freshwater could be shipped by way of backhauling by oil tankers to Saudi Arabia from Japan at a cost of between 0.83 and 1.16 USD/ton, including all infrastructure except distribution systems and excluding modifications to the tankers themselves. This cost level makes FWBH to a certain degree competitive with the chief water supply technology in the Middle East, desalination

Deducing sustainability by comparing FWBH with desalination has been done by calculating CO_2 emissions for unit volume transportation/production of freshwater (kgs/m^3) and harmful marine discharges. It is found that FWBH is not conclusively better than desalination in terms of GHG emissions. Emission level of FWBH is found to vary strongly with operational parameters. On the other hand FWBH can be a simple and potent solution to the seawater ballast water problem for regions with sufficient freshwater resources.

Viability of FWBH is found to be very dependent on oil market conditions, so to preserve some stability in water supply it is advised that handling of the water trade at a contractual level is done by public authorities. Accordingly, long term contracts can be considered more suitable for the purpose of FWBH than short term or spot contracts.

Feasibility of the FWBH concept is complex, and the question depends on mode of operation, location of ports and terminals, oil market conditions, ship type and several other factors. It is clear, however, that in many cases FWBH is the superior option compared to desalination, especially when including environmental aspects. Still, no FWBH project or scheme has ever been carried out. We conclude that the reason for this lies with authorities in both potential water importing and water exporting nations. Questions regarding the status of freshwater as an economic good has to be resolved on an international level, and oil exporting nations (especially Middle East countries) has to be convinced about the benefits of considering alternatives to desalination.

Keyword:

Freshwater, backhauling, water supply, water transport

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USE OF OIL TANKER RETURN/BALLAST SPACE FOR THE TRANSPORT OF FRESHWATER

A feasibility study

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PREFACE

This master thesis concludes our Master of Science study at the Department of Marine Technology, Norwegian University of Science and Technology (NTNU). The report researches the feasibility of a freshwater backhaul (FWBH) scheme using oil tankers.

Working on this topic has proven to be demanding, for two reasons. First, because it is a novel concept which has received very little attention from researchers and commercial actors, making it difficult to find accurate raw data. This has required us to “think outside the box” and base more of our conclusions on educated estimations than we perhaps have been used to. Still, we have retained a strong focus on providing a solid and systematic base for all our conclusions. Second, the holistic approach we aimed for meant that we needed to apply not only technical knowledge – as gained through our years at NTNU – but we also had to analyze and conclude on topics related to economics, environmental science and law. This broad focus has been demanding, but in turn it has been well worth the effort, as we believe it is almost impossible to judge the feasibility of any marine transportation idea without recognizing that technical aspects are far from the only limitations. As a result, we believe, this report answers some questions previous studies of FWBH have not been able to answer and provides the reader with a complete review of the concept.

We would not have been able to complete this report without the aid of some skillful and helpful people. First, we would like to thank Trygve Meyer, former Intertanko director, for kindly providing us with invaluable (and rare) research material as well as motivation. Without his assistance this report would undoubtedly be a very different one. Mr. David Murphy from the Cabinet and Policy Division of the Government of Western Australia also deserves a special mention for sending us related material and reports which have helped us in completing this report. We would also like to thank Mohamed Ali, Wilhelmsen Ships Service, Ebo Roek of Evides NV and Dragos Rauta from Intertanko for providing their thoughts on our topic.

Finally we extend our gratitude to our advisor, professor Stein Ove Erikstad, for coming up with the initial idea and helpful discussions along the way.

Trondheim, 14.06.2010

Pål Berg Lande

Vishal Sharma

Use of oil tanker return / ballast space for the transport of fresh water

Problem description

Aim/scope

The students will research the feasibility of using oil tankers return space and/or ballast water space for transporting fresh water. The report must assess fresh water demand, as well as both the technological and economical feasibility of such a system. This must be done on both a current and future scenario basis. All relevant regulatory issues should be taken into account. The environmental effects must be assessed, evaluating both emissions and other relevant environmental factors. The final report should provide a holistic conclusion regarding the concept of freshwater backhauling by oil tankers, both in economic, technical, legal and environmental terms.

Tasks

1. Analyze the fresh water demand, with respect to regions with fresh water scarcity. Look into the following both on a current and future scenario basis:
    - Climate change
    - Population growth
    - Increased standards of living
    - With respect to ports exporting oil via ships
2. Analyze the technological issues related to:
    - Ship side modifications
    - Port side elements (up/down-stream)
3. Perform an economical analysis to determine the feasibility of such a system, focusing on:
    - Complete lifecycle costs
    - Sensitivity
    - Comparison with alternative/competing solutions
4. Research the probable environmental impacts, with respect to
    - Ballast water management
    - Comparison of CO2 emissions from land based freshwater production VS oil tanker return space CO2 emissions
    - Oil tank cleaning residues
5. Assess regulatory and contractual issues related to freshwater backhauling by tanker

EXECUTIVE SUMMARY

This report analyzes the concept of using oil tankers' free cargo space and/or segregated ballast tanks to transport freshwater on the return leg, i.e. from oil unloading port back to oil loading port – also called freshwater backhauling (FWBH). The hypothesis considered is that by shipping freshwater this way to arid, oil exporting regions one can achieve a low cost and low GHG emission water supply system. The report analyzes the concept in a holistic manner, considering technical issues, transport and infrastructure costs, environmental impacts and contractual and legal issues.

Technically FWBH is feasible as the technical modifications and new infrastructure to be developed for FWBH can be integrated with the present oil tanker and trade infrastructure. Installing submersible pumps in each ballast tanks is seen as a flexible and efficient solution while demanding the least modifications to the oil tanker. Coating the ballast tanks with glass reinforced plastic or a poly urethane lining is the most effective corrosion inhibiting solution while protecting the integrity of water transported. For freshwater carried in cargo spaces no change in coating is advised as the residual oil would serve as a barrier between the water and the tank to inhibit corrosion. The final decision for selection of the best coating for SBT or cargo tanks can only be done by long term use and monitoring the coating selected. Use of Single point mooring (SPM) systems or another tanker cargo vessel which can be single hull is seen as a solution for loading and unloading the transported water. Selection of pipeline diameter, pumping station size and numbers, pipeline material and proper corrosion protection for the system is an important onshore technical parameter. The Manavgat river project in Turkey, which set up infrastructure for exporting freshwater, can serve as a practical example from which such technical parameters can be construed for future projects. Development of new technologies in offshore mooring, such as *HiLoad*, could in the future ensure appealing alternatives to SPM and could be utilized as a loading/unloading facility for FWBH. Once the freshwater is transported by ballast spaces the integration to existing water supply system and treatment of this water can be done with sufficient ease. The decision on the final treatment process is site specific for the origin of freshwater and may require some special treatment process, but a general treatment plant which uses gravity separation, flocculation and disinfection can be used to treat the transported freshwater to drinking water standards. For water mixed with oil, especially when carried in the cargo spaces gravity separation accompanied by filtration using synthetic resins/ceramic blocks can make the imported water fit for agricultural use, which can lead to niche "industrial agriculture" sites near oil terminals of the world which utilize freshwater carried by oil tankers in their cargo spaces.

Costs are estimated both on a general and scenario specific level. It is found that freshwater could be shipped by way of backhauling by oil tankers to Saudi Arabia from Japan at a cost of between 0.83 and 1.16 USD/ton, including all infrastructure except distribution systems and excluding modifications to the tankers themselves. This cost level makes FWBH to a certain degree competitive with the chief water supply technology in the Middle East, desalination. The picture is by no means conclusive, however, and the economical comparison between FWBH and desalination would have to be made on a case-by-case basis. Furthermore it is concluded that costs from FWBH can be lowered drastically if only ballast tanks are used and it is made possible to handle freshwater and oil simultaneously at the same terminal. FWBH is concluded to be much cheaper than using dedicated water tankers. Regarding the question of how much freshwater the vessel should load and carry on the return trip to minimize cost, we find that it

depends on the distance between oil unloading and loading ports as well as the distance the ship has to deviate to load or unload water, if any.

Deducing sustainability by comparing FWBH with desalination has been done by calculating CO_2 emissions for unit volume transportation/production of freshwater (kgs/m^3) and harmful marine discharges for the two technologies to decide the environmental performance. It was found that when desalination is done by Multi-stage flash (MSF) process, which is the most common desalination process in use in the Middle East, and using natural gas which is the least CO_2 producing fuel in comparison with coal and oil, the environmental performance in terms of CO_2 emissions for desalination is better than FWBH using SBT for up to 300,000 DWT tankers. When freshwater is carried in cargo spaces the per capita CO_2 emission reduces and improves the emission characteristics of FWBH in comparison with desalination. Forecasts for desalination predict more energy efficient processes which consume about one third of the energy consumed by a MSF process. In such a scenario FWBH by cargo or ballast spaces even for the largest tankers (500,000 DWT) has greater CO_2 emissions in comparison with desalination.

While comparing the harmful discharges to the marine environment the performance of desalination is particularly poor as it pollutes and harms the marine environment in multiple ways. FWBH on the other hand can be a simple and potent solution to the seawater ballast water problem for regions with sufficient freshwater resources. Further studies or research can be done in this field to analyze the feasibility of FWBH from a ballast perspective as a simple and easy solution in coping with ballast water conventions when it comes into force.

Viability of FWBH is found to be very dependent on oil market conditions, so to preserve some stability in water supply it is advised that handling of the water trade at a contractual level is done by public authorities. Accordingly, long term contracts can be considered more suitable for the purpose of FWBH than short term or spot contracts.

It is impossible to provide one single answer to the question of whether or not FWBH is feasible. It all depends on mode of operation, location of ports and terminals, oil market conditions, ship type and several other factors. It is clear, however, that in many cases FWBH is the superior option compared to desalination, especially when including environmental aspects. Still, no FWBH project or scheme has ever been carried out. We conclude that the reason for this lies with authorities in both potential water importing and water exporting nations. Questions regarding the status of freshwater as a economic good has to be resolved on an international level, and oil exporting nations (especially Middle East countries) has to be convinced about the benefits of considering alternatives to desalination.

LIST OF ABBREVIATIONS

API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
BWC	Ballast Water Convention
CoA	Contract of Affreightment
COW	Crude Oil Washing
DWT	Deadweight
EC	European Comission
EU	European Union
FWB	Freshwater Ballasting
FWBH	Freshwater BackHauling
GATT	General
GHG	GreenHouse Gas
IMO	International Maritime Organization
ISO	International Standards Organization
LoT	Load on Top
NAFTA	North American Free Trade Agreement
OCFW	Oil Contaminated Fresh Water
SPM	Single Point Mooring
TC	Time Charter
ULCC	Ultra Large Crude Carrier
VLCC	Very Large Crude Carrier
WS	Worldscale
WTO	World Trade Organization

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1 INTRODUCTION

Around the world, hundreds of millions of people lack access to clean freshwater. Increasing population levels and per capita consumption together with climate change is the driving force behind a renewed focus on alleviating water scarcity by increasing water supply. Completely different approaches have been proposed or put in use over the past three decades: Seagoing freshwater transport by tankers, towed bags or even icebergs; water diversion by pipe or canal, and desalination of salt- or brackish water.

Desalination is emerging as a primary water source in some areas, especially in the arid Middle East, but also in a number of island states, Spain and the United States. Although potentially a reliable source of large amounts of freshwater, desalination is regularly criticized for its negative impacts on the environment and its high costs. In many cases the only real alternative, though, is to transport water in from a distant source.

It is from this backdrop the idea of freshwater backhauling (FWBH) has emerged. Freshwater backhauling means carrying freshwater as a return cargo in ships which would otherwise travel in ballast condition, without cargo. The concept especially revolves around the idea of having crude oil tankers exporting oil from arid, oil producing countries carry freshwater on the way back. This report is limited to consider only crude oil tankers in the context of FWBH, although the concept could certainly be interesting for other ship types, such as bulk carriers and container vessels.

The concept itself is not new. As with many novel (and often environmentally beneficial) ideas, a lot of research went into it in the 1970s and 80s, following the turbulence in the oil markets in the 70s, but ceased abruptly once the economy recovered. The idea is that using the return trip to carry water results in lower costs and emissions per ton of water than would be the case with dedicated water tankers, while at the same time solving the problem of species relocation by seawater ballast. The theory is also that it would be superior to desalination in terms of both costs and environmental impact. Still, it has received little to no attention from any of the parties that would be potential beneficiaries in the execution of a freshwater backhauling project; today, it is seemingly forgotten in most discussions regarding water supply, emissions reduction and ballast water management. In our view the concept of water as return cargo in ships remains one of the few possibilities in shipping that is still both unexplored and highly realistic.

In this report we perform a holistic analysis of the freshwater backhauling concept. We aim to provide an accurate and up-to-date picture of all relevant aspects, including technical limitations and requirements, costs of implementation and economic sensitivity, legal and contractual issues and environmental impacts. Ultimately, the questions to be answered are [1] if FWBH is a feasible idea and [2] what technical, economical, legal and environmental issues must be considered and/or solved when realizing a FWBH trade.

Analyzing such a concept on a holistic level requires insight into the interplay between technical, economical and regulatory elements. As such we will rely on a wide range of sources, and strive to have a strong, interdisciplinary foundation behind each conclusion drawn. The final result should not only answer the question of feasibility, but provide the reader with a comprehensive understanding of what it is that promotes or prevents the realization of freshwater backhauling.

1.1 WATER – THE BIG PICTURE

> *"Water, like religion and ideology, has the power to move millions of people. [...] People move when there is too little of it. People move when there is too much of it. People journey down it. People write, sing and dance about it. People fight over it. And all people, everywhere and every day, need it."*
>
> *U.S.S.R. head of state Mikhail Gorbachev*

Water is one of the most vital resources for human survival but ironically it is also perhaps the most neglected. The UN suggests that an average person needs around 20-50 liters of water per day for basic needs like drinking, cooking and cooling. Studies by UN also show that currently there are around 894 million people around the world that lack access to safe and easily accessible drinking water and 2.5 billion people live in water stressed areas without basic sanitation(1). The aim of this chapter is to summarize the current state of affairs in global freshwater distribution and consumption and to look into different factors which will have an impact on the availability/distribution of freshwater in future. These factors in turn have an effect on the potential regions which can supply freshwater and that can benefit from possible freshwater backhaul by oil tankers (FWBH).

Freshwater constitutes 2.5% (Figure 1-1) of all the water on our planet and manifests itself in various physical forms and locations all of which are not directly usable for human consumption. Only about 0.03% of all water on our planet is freshwater which is available in the form of surface water and accessible groundwater for human consumption (2). The distribution of usable freshwater is not uniform nor does it follow the population distribution on the planet. For example, South America accounts for 25% of the total freshwater *run-off* while home to only 8.5% of the world`s population. On the other hand Asia, having 60% of the world`s population, can make use of 36% of global *run-off* (3). Another crucial factor which impacts the availability of freshwater is its timing and the seasonal influences. South Asia gets more than half of its water as precipitation during the monsoon season which lasts for 3 months a year (4 p. 23). These natural variations and cycles make water management and resource predictions complex and highly localized.

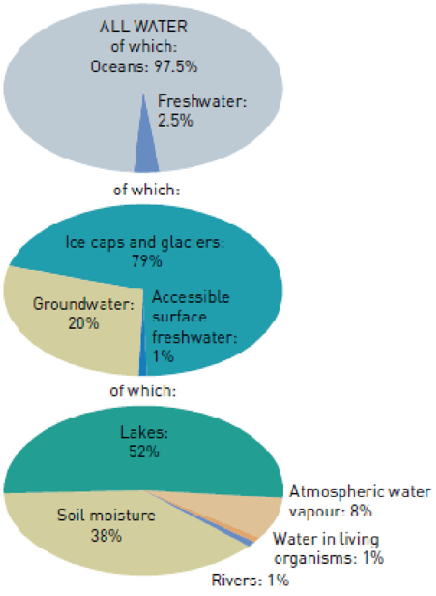

Figure 1-1: Available freshwater resources globally **Source:(5)**

Region	Population distribution[1] (6)	Renewable Freshwater Reserves -km^3/yr (% of World) (7)	Total Freshwater withdrawal-km^3/year (8)	Per Capita withdrawal-m^3/person/year(8)	Population without access to safe water (millions)(9)
N. / central America	5%	7,890 (18%)	622	1800	40
South America	8.5%	12,030 (28%)	164	471	40
Europe	11%	2,900 (7%)	392	516	0
Asia	60%	13,510 (32%)	2,294	555	710
Africa	15%	4,050 (9%)	213	205	370
Oceania	0.5%	2,404 (6%)	26	753	4.5

Table 1.1: Non Uniformity between freshwater and population distribution

Asia which holds large amounts of renewable water resources has a population of around 700 million people (Table 1.1) without access to clean freshwater for daily needs, these are people at the bottom of the economic strata of the society. The actual quantities required are larger than for basic human consumption needs. Much larger quantities of freshwater is required for industries and agriculture to propel the poorest people towards development, which calls for greater withdrawals in regions like Asia and Africa where the current withdrawal rates are already deemed to be unsustainable. Coupled with the fact that future population growth rates will be the greatest in these regions, the pressure to develop and manage water resources in these countries is certainly very high. Non-uniform distribution of water and seasonal variations of availability raise significant disparities between points of supply and demand within different regions, leading to areas becoming water stressed. North and sub-Saharan Africa, West and South Asia are some of the most water stressed regions in the world.

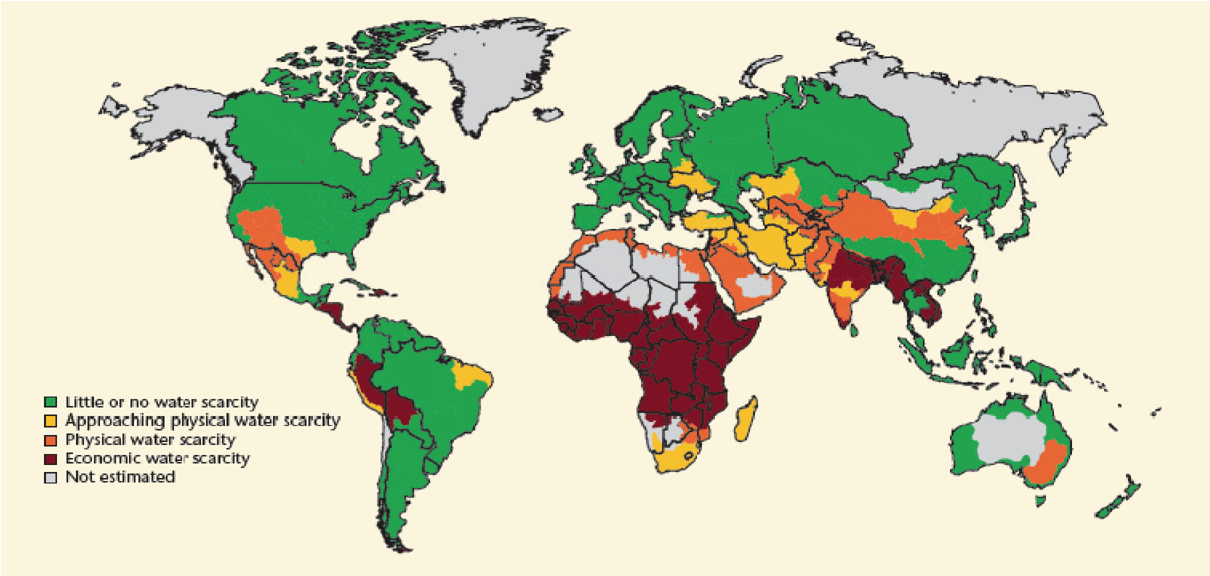

Figure 1-2: World freshwater stressed areas 2007 Source:(10)

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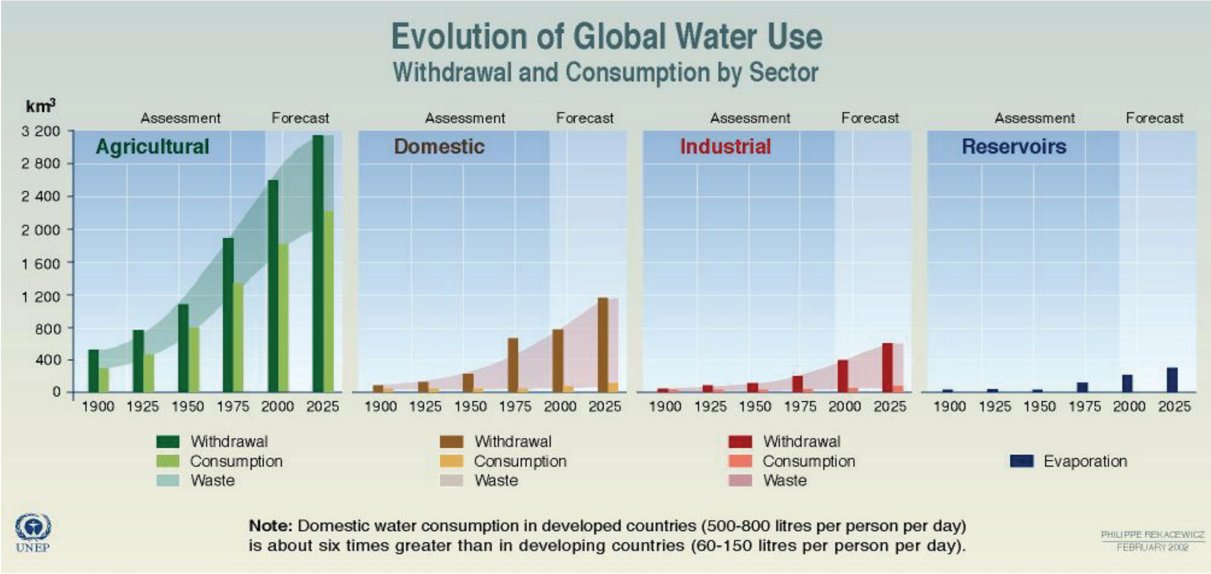
[1] World population in 2010 is estimated at 6.9 billion(103).

By 2025 about 1.8 billion people largely living in North Africa, Middle East, the Indian sub-continent and South Africa(11 p. 13) could face absolute water scarcity and around 5 billion people would face some kind of physical[2] or economical[3] water stress in their daily lives(12). Regions which would face severe economic water scarcity in the future are predominantly located in sub-Sahara Africa. Thus these regions arise as distinct potential FWBH beneficiaries if found plausible.

1.2 WATER USE IN DIFFERENT SECTORS

Freshwater usage can be broadly categorized into agriculture, industry and household. Agriculture accounts for up to 67 % of the total freshwater used in the world followed by industry at 20 % and household at 13% (Figure 1-3). The consumption patterns vary from region to region; while most of Africa, South Asia, Australia and parts of South America use water pre-dominantly for agricultural purposes, Europe and large countries like Russia, China and USA use water for industrial purposes (13).



Note: Domestic water consumption in developed countries (500-800 litres per person per day) is about six times greater than in developing countries (60-150 litres per person per day).

Figure 1-3: Water use in different sectors **Source: (14)**

1.2.1 AGRICULTURE

Water is important for achieving food security and is one of the biggest reasons for food related emergencies in developing countries (15). 70 % of food emergencies in 2002 were caused by water shortage and drought. Population demographics, warming of the planet due to climate change and economical prosperity leading to changes in quality of life (consuming more water intense food etc.) and quantity of food consumption induce further pressure on agriculture production and thus on water resources. Economic growth in countries like China and India has given rise to a vast number of people who consume more and better (16 p. 39). A welcome fact is that the world does have enough freshwater to produce food for people over the next half century (17 p. 2). This can be done without having to increase the agricultural water use by a large amount, according to the UN Food and Agriculture organization: *"FAO estimates that irrigated land in developing countries will increase by 34 percent by 2030, but the amount of water used by agriculture will increase by only 14 percent, thanks to improved irrigation practices"*.(15). The greatest potential to increase agricultural land area lies in the sub-Saharan region of Africa.

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[2] Physical water stress: Quantity of water resources insufficient

[3] Economical water stress: Sufficient quantities available for use if greater infrastructure development and water management pursued.

This is because of the physical suitability of the area for agriculture, but an additional advantage is that developing agriculture in this region will not only increase food supplies but also help eradicate poverty.

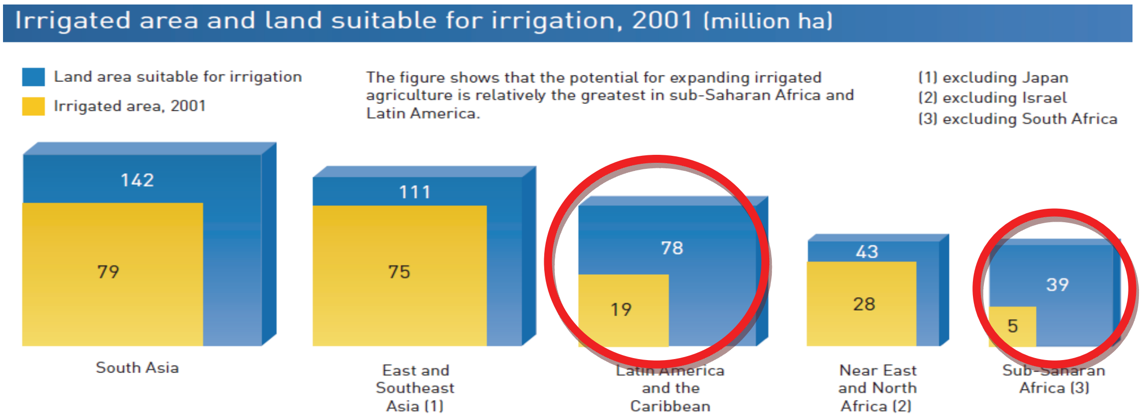

Figure 1-4: Areas most suitable for expanding irrigation (Source: (18))

Rain fed areas provides 60% of the world's food while responsible for 80% of agricultural area. Converting rain fed areas to irrigated land has a potential of increasing yield from 100-400 % (15). This necessitates constant and reliable supply of agriculture quality water, specially in Sub-Saharan Africa and the Caribbean where the potential of increasing irrigated land is the maximum and the regions are also close to major oil tanker routes of the world.

Large countries like India and China have started to face the effects of water scarcity leading to draught triggered food shortages. Over use of groundwater in India, has led to withdrawal of groundwater at unsustainable rates. Groundwater is being depleted at twice/thrice the rates of replenishment in India with aquifers being reduced by 1-3 meters every year(11 p. 9) . This has resulted in an environmental and economic disaster. Farmers find it more and more expensive to pump out the ever deepening groundwater, resulting in lesser incomes and reduction in food yield. The environment suffers from increase in toxicity in soil levels (phosphates, nitrates) and salinity, Pakistan being the biggest example of such pollution(11).

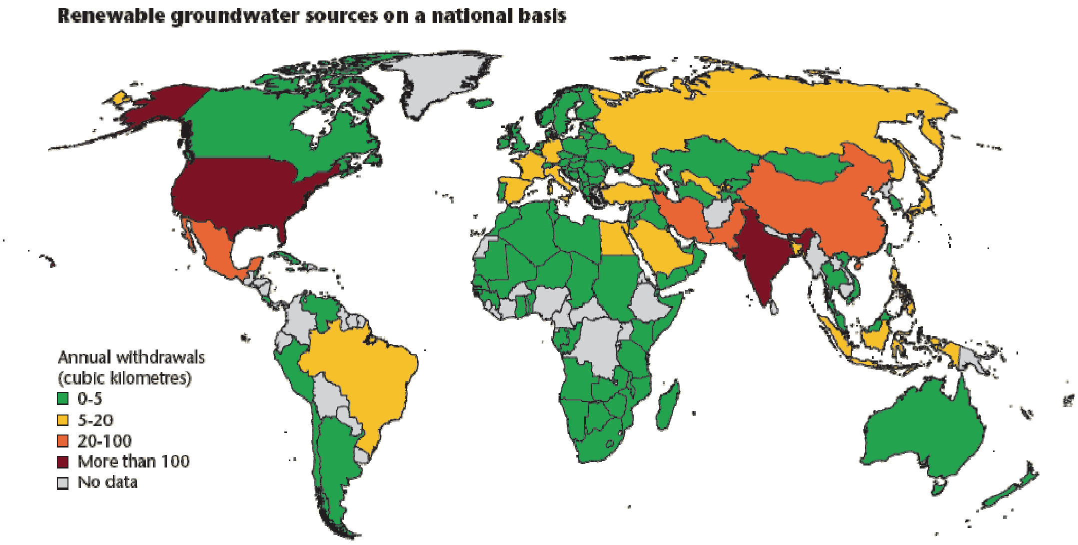

Figure 1-5: Annual withdrawals of groundwater (1995-2004) (Source: (16 p. 132))

Future forecasts for withdrawal by agriculture sector show an approximate 20% increase from 2600 km^3 in 2000 to 3100 km^3 (19 p. 121). Blue water or surface water is the major source for irrigation around the world. These surface water sources are renewed seasonally by precipitation. Changes in the amount of precipitation and duration of rainfall have a large impact both in the form of draughts or floods resulting in food related emergencies. The warming of earth`s atmosphere has caused intensification of precipitation events leading to greater number of floods or draughts in the past years (20). Changes in precipitation patterns can have large impacts on already developed water infrastructure for agriculture. Indonesia is an example of how climate change in the recent years has caused severe production losses (16 p. 114). There has been a shortening in the rainy season even though the total amount of precipitation has remained same or been slightly higher in regions of Bali and Java. This implies greater exposure to long dry periods with short flood like rainy periods causing existing agriculture infrastructure and water requirements to become unsustainable. Such areas can develop infrastructure to mitigate the extreme effects of climate change by making dams and other water intake structures which prevent floods and serve as potential seasonal supply of freshwater for FWBH trade.

1.2.2 INDUSTRY

Water in industry is used for direct production of goods like chemicals, petroleum, food products etc or in the energy sector, either for direct generation of power or for auxiliary purposes like cooling in a power plant. Water resources have a dual role, in acting as a consumable resource as well as a sink for effluents generated by human activities. Industries put pressure on water resources more by their harmful discharges and pollution by wastewater than by actual use. Industrializing developing countries have the greatest growth rate for freshwater consumption by industry. A rise of 55% in industrial water withdrawals has been predicated from 1995 to 2025 (7). In the developed world industrial withdrawal has been constant at 59% since the 1980`s (4 p. 29). Ever increasing power demand has a direct impact on increased water consumption for hydro-electricity and/or for cooling water. Most of the outflow from the production of hydroelectricity is used downstream for agriculture or household purposes. Also the volume for industrial purposes is very low, around 10% compared to the total withdrawals, because of substantial evaporation in reservoirs (16 p. 116). The efficiency of freshwater use versus withdrawal has a large variation between different industries, for example water used for cooling in industry which is also the main industrial water consumer is only 5%(16 p. 118). This is mostly because of losses due to evaporation in the reservoirs or cooling lakes. Developing a system which can reduce these evaporation losses significantly (for example having covered or sheltered reservoirs) can be useful from a FWBH perspective. Using such industrial facilities with water infrastructure already in place and further developing them to act as a source for freshwater in FWBH trade can help improve the productivity and efficiency of water usage at the same time reducing the investment costs for FWBH system. Asia will constitute to more than 40% of growth in electricity until 2030, most of which would come from coal or other fossil fuel consuming plants (4 p. 30) which would require large amounts of cooling water. These sites represent potential source of freshwater which may be exported after catering to local freshwater demands.

Pollution by industry by way of wastewater discharge is a big constraint on global freshwater supplies. Areas of high industrial activity may lead to pollution and contamination of surrounding surface water resources. Having a knowhow of such areas supplies information regarding potential users of FWBH and water sources which should be deemed unfit without prior treatment for FWBH. The knowledge of type and extent of pollution on natural water resources in different areas around the world will give an idea about any pre-treatment facilities needed so as to eliminate any harm to the environment or the vessel in case these resources are used for FWBH. Table 1.1 illustrates different regions around the world and the type of contamination in freshwater resources. Sources of freshwater in Nordic countries present a low contamination and sediment sources ideal for FWBH.

Continental area	**Extent and type of pollution in surface water**
Africa	Major sources of pollution in Africa, are fecal contamination; toxic pollution downstream of major cities, industrial centers, and/or mining; and vector-borne diseases.
Americas	In the United States and Canada, the major pollution problem is eutrophication from agricultural runoff and acidification from atmospheric deposition. Major problems include persistent toxic water pollution. In South and Central America the major contaminant problems, (except in the Amazon and Orinoco basins), are pathogens and organic matter, as well as industrial and mining discharges of heavy metals and pesticide and nutrient runoff.
Asia and the Pacific	In the Indian subcontinent the major problems are pathogens and contamination from organic matter. While these are prevalent in Southeast Asia as well, heavy metals, eutrophication, and sediment loads from deforestation are also critical in this sub-region. The Pacific Islands have higher levels of salinity than other regions in Asia, while still having problems with pathogens and organic matter, like much of the developing world. China has a combination of all pollution problems in its major watersheds. In the dry north, eutrophication, organic matter, and pathogens are major problems, while in the south in addition there is a large sedimentation problem. Finally, Japan, New Zealand, and Australia present similar pollution problems as other industrial nations.. Australia has particular problems with salinity due to agricultural practices, especially in the Murray-Darling Basin.
Europe	In the Nordic countries the major problem is acidification, while other contaminant levels are relatively low. In Western Europe eutrophication and nitrates pose the greatest challenge, while in Southern and Eastern Europe the major contaminants are organic matter and pathogens, nitrates, increasingly pesticides, and eutrophication.
Eastern Mediterranean	Industrial pollution and toxics are a problem in some locales, but overall salinization from over abstraction is the key concern in this region

Table 1.2: Water Pollution Causes: World Source: (21 p. 183)

1.2.3 DOMESTIC

World population demographics and growth are directly related to the amount of water withdrawn for municipal purposes. Global human population is expected to rise to 9.1 billion by 2050 (6). By 2050 it would be the first time in human history that majority of population will reside in cities. Also more than half of this urban population in 2050 will live in cities in developing countries. Mega cities with population greater than 10 million will rise with a responsibility to supply clean and safe drinking water and access to sanitation to its dwellers.

Sewage and wastewater arising from cities lead to an additional water stress by polluting the available water resources. It has been estimated that in developing countries almost 90-95% of all sewage is released untreated into surface water (4 p. 31). Without safe and cheap water access to the future and current mega-cities, water procurement costs and indirect costs due to spread of diseases and thereby reduction in productivity will create a large financial burden. If water sources for FWBH are located near major cities in the developing world the water should be tested and/or treated for sewage removal and other harmful human and animal pathogens.

Availability of a reliable source of drinking water and sanitation leads to reduction in poverty and a net positive contribution to economic development. Developing water storage capacities and investing in water development infrastructure are some of the ways in which freshwater can be made available. For example, Ethiopia has only 43 m^3 per capita water storage capacity;

the variations in the GDP of Ethiopia follow closely the variation in rainfall in the country (Figure 1-6). Also in view of future climate change and intensification of hydrological cycle, as seen before countries residing in arid and semi-arid regions will face large reductions in precipitation. This would lead to water stress in highly dense cities of these regions. Investing in water infrastructure is the way forward for such countries like Ethiopia, Kenya and other South Asian countries to make water a positive force for their economies.

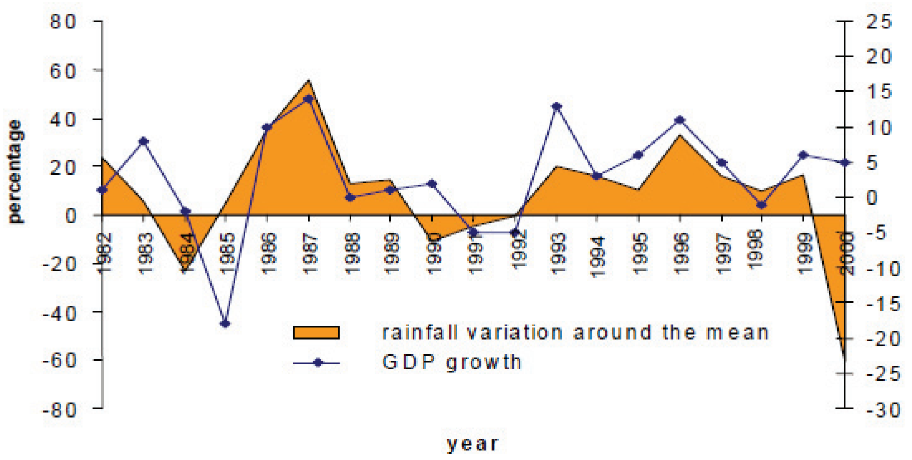

Figure 1-6: Rainfall variation and GDP Ethiopia Source:(22 p. 5)

For future development such countries which face an economic water shortage and have considerable amounts of freshwater resources, the investment in water infrastructure should be done in a way such that extending those storage and treatment facilities to provide or receive water from FWBH as the case may be, can be incorporated with relative ease. Until such time the economically freshwater stressed countries can utilize FWBH trade for supplying relatively cheaper alternative of water source.

Thus the initial insight into the state of water resource of the world shows that sufficient quantity of freshwater is naturally available to sustain the human population for at least the next half century. The dilemma in utilizing these resources sustainably has two facets; one caused by nature by way of uneven distribution of the resource and the other by humans by wasteful use and unsustainable extractions. Anthropogenic climate change further complicates the matter at hand by intensifying the hydrological cycle and having the greatest impact in terms of reduction in rainfall on semi arid regions which already face some water stress. The result of the impact leads to changes in the existing freshwater supply infrastructure to incorporate measures to mitigate the effects of harsh and intense rainfalls and provide water for the longer dry periods.

The aggregate effect of human and natural factors on freshwater supply and demand today is perhaps the most skewed in the history of modern civilization. Modern technology has provided solutions like desalination, waste water treatment etc to correct these effects to some extent, but at a monetary and environmental expense. It is interesting to analyze if FWBH can lead to environmentally and economically inexpensive solution for freshwater supply especially to oil exporting countries in Middle East and West Africa and other water scarce regions on oil trading routes.

1.3 UNCONVENTIONAL WATER SUPPLY TECHNIQUES

Humans have thousands of years worth of history of inventing technologies that increase the amount of available freshwater beyond that which can be extracted from rivers or lakes. Simple artificial dug wells provides access to underground water and has played the most dominant part in freshwater supply since ancient times, and wells remains very important in most parts of the world. As explained in the previous chapter, however, in some regions there is not enough water present to feed the demand. When relocating large amounts of people is not an option, and conservation measures and water re-usage cannot provide sufficient mitigation, other options must be explored to increase supply.

This chapter will review different ways of increasing the amount of freshwater available to consumers in areas of the world suffering from water scarcity. We will only focus on means that increase supply, recognizing that conservation programs and wastewater treatment systems are very important but noting that supply must still be substantially increased in many areas. We will attempt to provide accurate and up-to-date data and review the current scientific consensus regarding the feasibility and maturity of each measure. This is done to afford the reader with an understanding of the current state of unconventional water supply research and development, and to establish a qualitative and quantitative basis with which to compare freshwater backhauling.

1.3.1 DESALINATION

The concept of desalination is not new; methods for separating salt from water have been known since ancient times, but it remained a specialty process until the second half of the 20th century. Over the last fifty years desalination has emerged as an important water source in some regions, especially in the Middle-East, where more than 70 per cent of the world's total desalination capacity is installed(23),(24 p. 273).

The share of worldwide consumed freshwater that comes from desalination is currently very low; it is estimated that globally, desalination is the primary freshwater source for about 75 million people (25), accounting for less than 1% of world demand (23). The primary drawback of desalination is that the energy cost of converting salt water to potable water is very high. However, recent advances in desalination efficiency, both economic- and energy wise, coupled with rapidly increasing water scarcity, has led to a surge in desalination popularity. The UN estimates that world desalination capacity will be doubled from 2004 to 2025 (16 p. 155).

There are several different ways in which sea water can be desalinated, though all involves introducing the water to large amounts of energy. The two major processes in use today are multi-stage flash distillation (MSF) and reverse osmosis (RO). Put simply MSF is a thermal process, and works by adding heat and having water evaporate, leaving the salt behind. It is the most widely used technology today, accounting for 61.6 % of all seawater desalination in 2002. RO is a membrane process, using pressure and filters to remove the salt, and had a 26.7 % share of seawater desalination in 2002 (25).

Type	Total dissolved solids
Freshwater	<1500
Brackish water	1500-10000
Salt water	>10000
Standard seawater	35000

Table 1.3:Water classification based on salinity **Source: (24)**

Both processes are currently receiving a lot of attention in terms of research, but energy consumption remains high, partly explaining why desalination only has become widespread in the energy rich Middle East. The MSF processes typically require 4kWh electrical power per m^3 produced freshwater, while RO processes typically consume 6-8 kWh/m^3, however new developments may allow both membrane and thermal processes to desalinate water whilst consuming as little as 2kWh/m^3 in the near future (25),(24).

The fact that desalination is so energy intensive means that the choice of energy source is important. Most plants, at least in the Middle East, are at present powered by fossil fuels and thus contributing to increased emissions of greenhouse gases (GHG). Due to the high thermal energy consumption of distillation most MSF plants in this region use cogeneration: making use of excess heat from power production plants in addition to electrical power. Alternatively plants could be powered by excess heat from nearby nuclear power plants or other industrial facilities, or renewable energy (RE) sources such as wind, geothermal and solar power could be brought into play. In fact, most of the areas suffering from water scarcity have an abundance of sun and/or wind, and therefore a lot of research is currently going into the field of desalinating water using RE.

1.3.1.1 Costs

Attempting to estimate costs for desalination is difficult, as it depends very much on the technology used, the energy source, feed water salinity and other aspects of location, and several other factors. Soldatos and Karagiannis (26) presented in 2007 an extensive review of desalination costs, examining almost 100 different desalination projects, powered both by conventional and renewable energy sources. They conclude that the lowest obtainable cost for desalting seawater is 0.47 USD/m^3, using conventional energy sources and large scale facilities. However costs climb sharply when economies of scale are not fully exploited, when RE is the primary energy source and when the physical conditions of the site are not optimal.

Type of feed water	Size of plant (m^3/day)	Cost (USD / m^3)
Brackish	<1000	0.84-1.41
	5000-60000	0.28-0.57
Seawater	<1000	2.37-12.00
	1000-5000	0.75-4.20
	12000-60000	0.47-1.73
	>60000	0.53-1.07

Type of feed water	Type of energy used	Cost (USD / m^3)
Brackish	Conventional	0.28-1.41
	Photovoltaic	5.00-13.75
	Geothermal	2.67
Seawater	Conventional	0.47-3.60
	Wind	1.33-6.66
	Photovoltaic	4.18-11.99
	Solar collectors	4.66-10.66

Table 1.4: Desalination costs **Source: Aggregated from Soldatos & Karagiannis (26)**

1.3.1.2 Environmental

Perhaps the largest drawback of desalination is the negative effects such plants have on the environment. The aforementioned GHG emissions is but one of the issues. Desalination projects make use of large land areas, especially when co-located with power plants, and adversely affects the marine environment by sucking marine life into the water intakes and discharging concentrated brine and chemicals into the sea.

Desalination plant intakes can either be open intakes, or intakes below ground, embedded in the seafloor. Open intakes are the worst in terms of negative impacts on marine life, sucking in and destroying eggs, larvae, plankton and other smaller organisms. Larger organisms can be pinned to the outer filter or grating and be suffocated or starved. The effects on ecosystems are especially severe in areas where multiple desalination plants are located in the same area, such as in the Red Sea or Arabian Gulf (24 pp. 277-279). By reducing the intake flow velocity or employing below ground intakes these effects can to some degree be prevented, but this might reduce plant efficiency and increase costs, and whether or not it is viable to do so is to a large degree site specific (27).

The substances removed from the source water must be discharged, and this is usually done straight into the sea close to the plant itself. Salt is discharged in the form of highly concentrated brine, but the discharge water also contains chemicals used in pretreatment, biocides, antiscaling and anticorrosives, and heavy metals from corrosion. In the case of thermal distillation plants the reject water also has an elevated temperature. The exact reject water composition varies quite a lot between plants with different desalination technologies. Also, the area affected varies, as RO reject streams concentrate spread over the sea floor, affecting bottom dwelling organisms, whilst thermal distillation concentrate has a lower density and affects open water organisms (28). It is well documented that by thoroughly dispersing the brine in a large area high salt concentrations can be avoided and thus impacts to marine life minimized, but this is most likely not valid for discharged chemicals and heavy metals(24 p. 283).

These effects are additive when several plants are located in the same area, and become especially impactful when the sea area in question has low circulation, such as the semi-enclosed Arabian Gulf. Over the recent years the environment in the Gulf Sea has been degraded. Land based activities have been identified as the main source of pollution, with desalination plants playing a major role. Plants in the Gulf area are predominantly of the MSF type, continually discharging a total of 1000 m^3/s waste water into the sea (24 pp. 289-290). Although much larger, and with a surrounding desalination capacity lower than that of the Arabian Gulf, the Red Sea suffers from the same effects.

Even though many papers have been published discussing the possible and likely environmental impacts from desalination plants, there is still a large level of uncertainty. The US National Research Council of the National Academies stated in 2008 that there is a *"surprising paucity of useful experimental data, either from laboratory tests or field monitoring, to assess these impacts"* (29 p. 126). The below table, taken from the 2009 article "UNEP resource and guidance manual for environmental impact assessment of desalination projects" (30), summarizes the chief environmental concerns related to desalination projects.

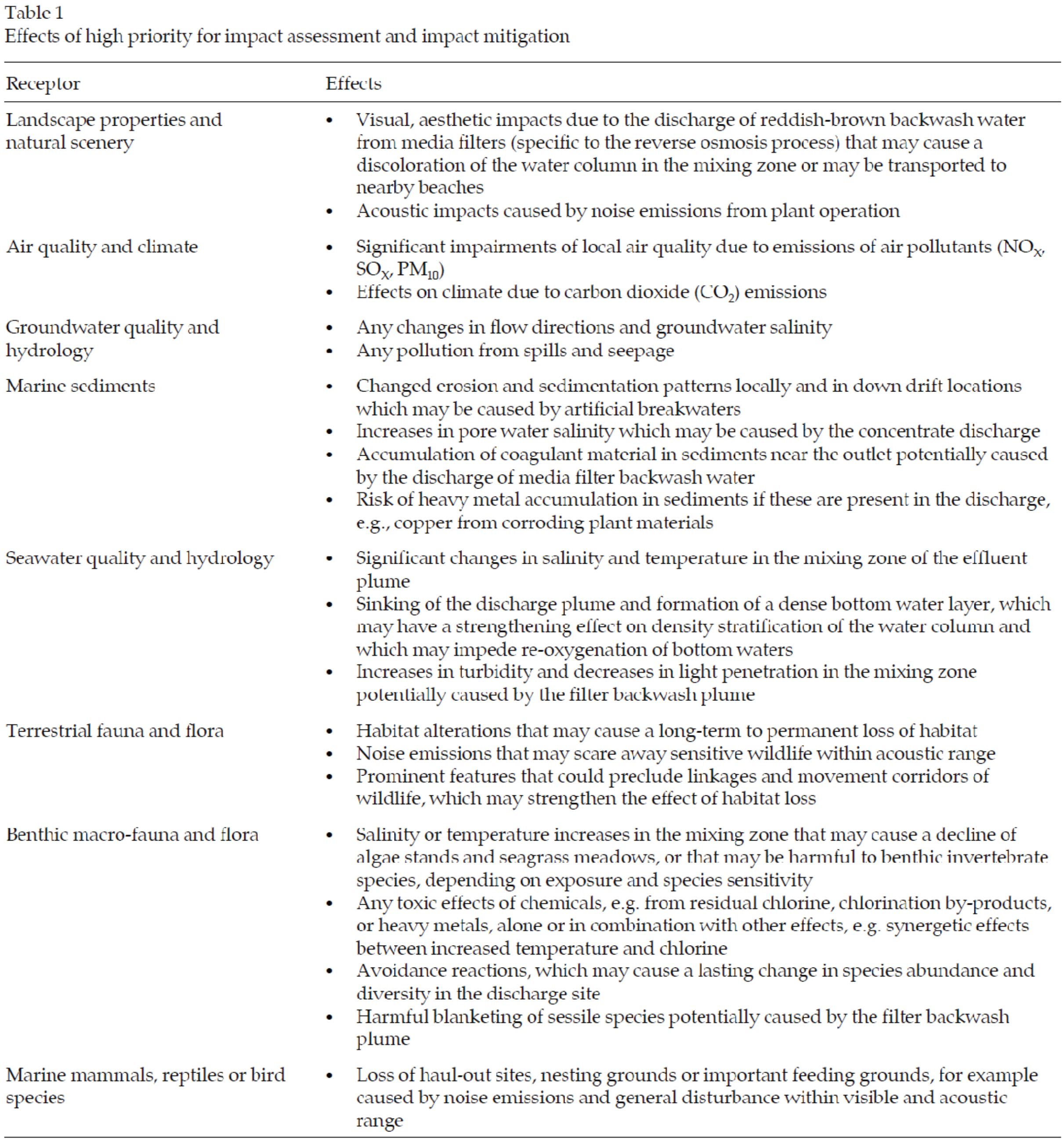

Table 1
Effects of high priority for impact assessment and impact mitigation

Receptor	Effects
Landscape properties and natural scenery	• Visual, aesthetic impacts due to the discharge of reddish-brown backwash water from media filters (specific to the reverse osmosis process) that may cause a discoloration of the water column in the mixing zone or may be transported to nearby beaches • Acoustic impacts caused by noise emissions from plant operation
Air quality and climate	• Significant impairments of local air quality due to emissions of air pollutants (NO_X, SO_X, PM_{10}) • Effects on climate due to carbon dioxide (CO_2) emissions
Groundwater quality and hydrology	• Any changes in flow directions and groundwater salinity • Any pollution from spills and seepage
Marine sediments	• Changed erosion and sedimentation patterns locally and in down drift locations which may be caused by artificial breakwaters • Increases in pore water salinity which may be caused by the concentrate discharge • Accumulation of coagulant material in sediments near the outlet potentially caused by the discharge of media filter backwash water • Risk of heavy metal accumulation in sediments if these are present in the discharge, e.g., copper from corroding plant materials
Seawater quality and hydrology	• Significant changes in salinity and temperature in the mixing zone of the effluent plume • Sinking of the discharge plume and formation of a dense bottom water layer, which may have a strengthening effect on density stratification of the water column and which may impede re-oxygenation of bottom waters • Increases in turbidity and decreases in light penetration in the mixing zone potentially caused by the filter backwash plume
Terrestrial fauna and flora	• Habitat alterations that may cause a long-term to permanent loss of habitat • Noise emissions that may scare away sensitive wildlife within acoustic range • Prominent features that could preclude linkages and movement corridors of wildlife, which may strengthen the effect of habitat loss
Benthic macro-fauna and flora	• Salinity or temperature increases in the mixing zone that may cause a decline of algae stands and seagrass meadows, or that may be harmful to benthic invertebrate species, depending on exposure and species sensitivity • Any toxic effects of chemicals, e.g. from residual chlorine, chlorination by-products, or heavy metals, alone or in combination with other effects, e.g. synergetic effects between increased temperature and chlorine • Avoidance reactions, which may cause a lasting change in species abundance and diversity in the discharge site • Harmful blanketing of sessile species potentially caused by the filter backwash plume
Marine mammals, reptiles or bird species	• Loss of haul-out sites, nesting grounds or important feeding grounds, for example caused by noise emissions and general disturbance within visible and acoustic range

Figure 1-7: Environmental impacts from desalination plants Source: (30)

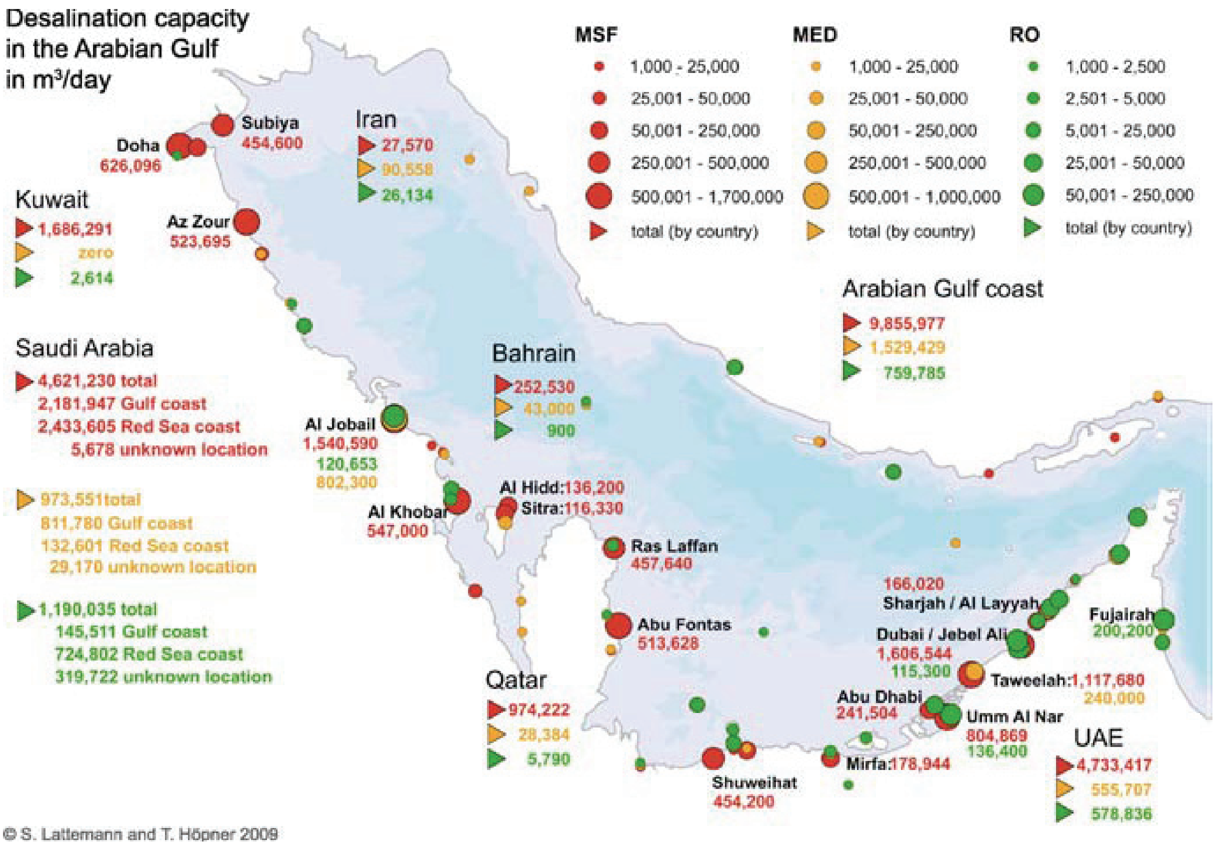

Figure 1-8: Desalination capacity in the Arabian Gulf **Source: (24)**

1.3.2 TRANSPORTATION OF FRESHWATER

In many cases the most economical and environmentally safe way of mitigating water scarcity is through conservation, storm- and rainwater harvesting/storing and water recycling. In order to properly assess different alternatives for increasing water supply, though, we will assume that for any scenario we look into these measures are already in place or unfeasible. This leaves options in which water is physically transported from some place with surplus water to a place lacking water.

1.3.2.1 Pipelines or canals

Perhaps the most famous example of the fact that supplying population centers with water from a good distance over land is an old idea are the ancient Roman aqueducts. Artificial canals, aqueducts and, in more recent times, pipelines, are vital for the supply of water in most parts of the world.

Being the historically preferred option in many places, canals are still being constructed today. The primary drawback is that a canal must follow the contours of the land, and although pumping stations can be built to increase water throughput this makes canals very nonflexible. Forming a land barrier throughout its length, it also intrudes on the environment and can disrupt ecosystems and habitats. Finally, leakage and evaporation will always occur, which means that the transport efficiency of a long canal is low. A canal will require water treatment and in some cases several pumping stations, so it does consume energy. As water tends to find its own way it will over time alter the layout of the canal itself, costs and energy consumption related to maintenance can be high.

A pipeline is a good alternative to canals when the water must be transported over – or through – hills, or when the water is at risk of being contaminated or evaporated along the way. When the geographical conditions allow it, long distance pipelines are an attractive option for increasing water supply, as the environmental impact from pipelines is small compared to desalination plants and, to some degree, canals. Still, pipeline construction can be quite intrusive and the necessary infrastructure, such as pump stations and treatment facilities, can use up much land and does require a lot of energy. Just as for desalination, costs for pipelines vary greatly with the prevalent physical conditions; distance, required lifting height and pressure, pipe diameter and the materials chosen significantly affect costs. Today, long distance pipeline projects are being proposed or already implemented as part of a solution to water scarcity, notably in the US, Australia and Brazil.

Australian authorities published in 2006 a report evaluating different alternatives for supplying Perth on the southwest tip of Australia with water from the Kimberley region in the northwest. The distance overland between these regions is approximately 2000 km, and $200 \cdot 10^9$ m^3 of water should be transported per year. The report “Options for bringing water to Perth from the Kimberley” (31), although restricted to one specific region, provides useful insight into the properties of long distance pipelines and canals. It concludes that due to leakage and evaporation, a canal would have to move twice the volume of water compared to a pipeline. A canal would also have to be 3700 km long, compared to 1900 km for a pipeline, as it would have to follow the contour of the land. Important energy consumption and cost figures from the report are outlined in Table 1.5.

Overland water transport method	Distance [km]	Energy consumption [kWh/m³]	Costs [USD/m³] total[4]
Pipeline	1900	5.80	9.83
Canal	3700	3.70	12.38

Table 1.5: Pipeline vs. canal costs for transporting $200 \cdot 10^9$ m³ of water across Western Australia per year **Source: (31)**

1.3.2.2 Iceberg utilization

Icebergs are an enormous untapped freshwater source. The annual amount of iceberg melting water is close to the global freshwater consumption, at $3 \cdot 10^{11}$ m³ (32). The concept of utilizing icebergs as a freshwater source revolves around two ideas: Towing them from Polar Regions to coastlines of water scarce areas - or harvesting them in situ, i.e. filling up tankers or floating bags with melt water and shipping to port. The topic was widely discussed in the 1970s, when several papers were published concluding that towing icebergs from Antarctica to, amongst other places, South Africa, Australia and Saudi Arabia would be a feasible and cost efficient way of increasing water supply[5]. However at the time the technology to tow the huge icebergs required for the operation to be economic did not exist. In addition costs were compared with desalination, which at that time was in its early stages and had very high costs compared to the current day – perhaps making iceberg towing seem more feasible than it in reality is.

Icebergs have been considered as a potential water source for some time, especially for countries close to the Antarctic. In 2006 authorities in London discussed towing icebergs from Greenland or the Arctic to the Thames River to alleviate water shortages, but these plans have since been abandoned (33). Spandonide (2008) proposes wrapping icebergs in huge bags in situ, allowing the water to melt, and then harvesting the freshwater, and transporting it in floating bags(32) as mentioned in chapter 1.3.2.3. He outlines progress made in the fields of materials for wrapping and bags, iceberg detection and selection and water loading and unloading. Still, apart from iceberg diversion operations in North Sea oil fields, no attempts have yet been made to tow or harvest an iceberg on a large scale, nor has up-to-date cost estimates been made. The question of whether or not the concept is viable remains untested, and enough progress has not been made since the 1970s, leaving the concept on the drawing table still.

1.3.2.3 Dedicated tanker, barge or bag transport

Especially for small island states the use of ships or barges to supplement water supply might be attractive. It might often be the only cost-effective option available, as distances are usually too large to accommodate pipelines, and desalination is not cost-effective at smaller scales and requires far too much power. Island states in the Caribbean, such as Antigua, St. Thomas and Barbados received water via barge or tanker in the 1980s and 1990s. The small island state of Nauru, in the pacific, received 30% of its water from tankers in the same period (34). Other noteworthy trades include Turkey's export of water to North Cyprus and Israel, and the port of Marseille's water export scheme – using converted vegetable oil tankers – to Spain and Italy in the 1980s (35).

Since 1990 several companies have been set up around the idea of manufacturing giant floating bags, meant to be filled with water and towed by tug to water scarce regions. One such company, Aquarius Water Transportation, successfully operates a fleet of eight 720m³ and two large 2000

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[4] Including capital, operational and maintenance costs.

[5] See Al Faisal 1977 (89), Quinn 1978 (90) and Job 1977 (91). The unusual peak in iceberg utilization interest in the 70s can largely be attributed to Prince Al Faisal of Saudi Arabia, who organized and funded a series of conferences on the subject.

m^3 flexible polyurethane bags. The bags are towed by tugs, and linked to the main water supply on the offloading-side shoreline via flexible pipes. The company has been using these bags to deliver potable water to Greek islands since 1997. We have, however, been unable to find any other example of successful implementation of floating bags as a means of water transportation. Another company, Norwegian-based Nordic Water Supply, landed a contract to supply North Cyprus with water from Turkey using bags in 1997, but the water bags were prone to bursting and the company filed for bankruptcy in 2003 (35),(36).

Table 1.6 below contains cost estimates for various barge, tanker and bag projects from different sources. Priscoli and Wolf (2009) reviews transportation costs for several of the aforementioned projects. Most of the figures listed, though, are in 1980s or 1990s US Dollars. However Priscoli and Wolf conclude that transportation by water tanker is still the most viable option today and that the relevant technology has not changed much, so *“the prices stated* [...] *may not be dissimilar to those that would be expected for a similar transport in the current day”* (34 p. 259). UNEP (1998) states when it comes to transporting freshwater to islands, barges or tankers are very expensive. They state higher costs than Priscoli and Wolf, but this is to be expected as vessels going to small islands would have to be small themselves due to port-side limitations, whereas ships going from Turkey to Israel or Cyprus can take advantage of economies of scale to a higher degree. Costs related to floating bag transportation is harder to come by, as the technology is still very much in early stages of development, however some figures are included in the below table.

Method of transportation	Costs [USD/m^3]	Distance [km], one way	Location	Vessel size	Yearly transport [m^3]	Year	Source
Barge/tanker	1.40-5.70	100-1000	Caribbean	NA	NA	Mid 1980s	(37)
Barge	7.65	100	Caribbean	NA	NA	early 1980s	(37)
Barge	0.70	240	Caribbean	32000 m^3	NA	1983	(38)
Barge	0.60	970	Caribbean	65000 m^3	NA	1983	(38)
Tanker	0.80	600	Turkey-Israel	NA	50 Million m^3	2003	(34)
Tanker	0.40-1.10	250	Turkey-Cyprus	NA	40000 m^3	1999	(34)
Tanker	5.48	2200	Australia	500.000 DWT	200 Million m^3	2006	(31)
Tanker	1.35-2.10	3000	USA	250-325000 DWT	NA	2001	(34)
Water bag	0.85-1.51	900	Australia	NA	182.5 Million m^3	2008	(39)
Water bag	5.50	2000	Australia	500.000 m^3 bag	200 Million m^3	2006	(31)
Water bag	1.00-2.00	21	Greece	750 m^3 bag	290000 m^3	2001	(40)

Table 1.6: Cost estimates for freshwater transport with marine vessels, various sources

The high degree of variation between the figures listed in the table can to a large extent be attributed to the fact that widely different projects are included. It is evident that economy of scale is important in the transport of freshwater, just as for other marine transport trades. It is interesting, however, to note the big difference between Spragg & Associates' (39) and the Kimberley Water Supply Panel's (31) cost estimates when it comes to huge floating bags. The yearly transport demand in both analyses is fairly equal, and the bag size would also most likely be similar, but one estimate is 5-6 times as high as the other. This only proves to show the difficulty in predicting costs for a completely new and novel technology, and points out that bags of this size is quite a few years ahead still. It is also important to note that many of the estimates above are close to the cost estimates for desalination listed in Table 1.4. Still, loosely assuming a average cost of desalination at 0.70 USD for modern developments, it seems that dedicated tanker transport would have trouble competing. A report prepared for the government of Newfoundland and Labrador in 2001 analyzing the feasibility of export of bulk water concluded that *"Tanker transport costs, at moderate or high rates, make bulk water export uneconomic"* (41).

Despite the examples mentioned above, the extent of seaborne freshwater transport remains very limited today. UNEP (1998) states that it is rarely used *"except during emergency periods"* (37). Anderson and Landry (2000) find that apart from barges and small tankers supplying small amounts of water, *"no company is commercially exporting water by way of large tankers"* (40). A Global Water Intelligence (2005) article quotes a senior partner in a New Jersey based water transportation company, claiming that there might be as little as 20 tanker loads a year on the spot market (35). As outlined in chapter 5, in many countries there is much resistance against exporting freshwater in bulk, and the legal aspects of international bulk water trade remains unclear.

1.3.2.4 Ship return space

Another way of enabling international seaborne trade of freshwater is to use as a substitute for ballast water and/or carry it as backhaul cargo in tankers trading between water rich and water scarce ports. Looking at oil exporting ports in arid regions, such a scheme would theoretically allow these ports to augment their water supply in a very energy efficient way, as the tankers would have to fill up with ballast water on their return trip anyway. Even though the ship itself consumes oil and emits GH gases, theoretically no *additional* emissions occur with the increased water supply. Brewster and Buros (1985) argue that third world countries with surplus freshwater could benefit greatly from exporting water in this way, *"possibly under swap arrangements with arid oil exporters"* (38). As presented in the previous chapter, use of dedicated tankers for freshwater transport is viewed by many as being too costly compared with other options, notably desalination. If turnaround time in port does not increase too much, freshwater transported as return cargo, especially as ballast, would add minimally to the ship owner's existing costs and as such make return cargo a cheaper option than dedicated vessels. If segregated ballast tanks are used for carrying freshwater, a third advantage of this concept is that the need for costly ballast water cleaning systems is eliminated. Ballast water management is a topic that is receiving a great deal of attention at the time of writing, with the IMO "International Convention for the Control and Management of Ships' Ballast Water and Sediments" requiring most ships to put into service ballast water treatment systems before 2016[6].

The use of return space for carrying of freshwater remains an untested idea and has received relatively little attention with regards to research. One of the very few papers published on the concept was commissioned by Nippon Kaiji Kyokai (ClassNK) and released in 1985. The

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[6] This date is as of yet uncertain, as the required number of states has not yet ratified the convention.

research committee constructed 56 different combinations of port facilities, tank usage, tank washing, ship type etc. to analyze the viability of the concept in various scenarios. They found that with some changes to pumping and piping systems, the use of freshwater as return cargo and ballast in segregated ballast tanks would be feasible in many cases. Water could be carried in the normal cargo tanks, but the viability of this was found to depend heavily on 1) demands to water purity, and 2) port side water treatment facilities availability and costs. The study primarily covers the practical and technical aspects of the topic, and as such concludes that – apart from lacking port-side infrastructure – it would not be difficult to implement. Moreover the report is quoted: *"The previously mentioned 56 combinations were studied, with the conclusion that all 56 could be implemented, and would, with few exceptions, contribute to reducing ocean pollution"* (42).

The small island nation of Nauru received up to one third of its freshwater as return cargo on phosphate tankers in the 1980s and 90s (34). However since most of the phosphate now is depleted, RO desalination has taken over as one of the primary water sources (43).

One question that quickly arises, given many of the obvious advantages of utilizing tanker return space, is, why has it not already been done? The huge developments in the Middle East over the past decades failed to trigger sufficient demand for such a trade. Again, such a trade would not have been difficult to put into operation, as most incoming tankers the last 20 years arrived with thousand of tones of water in segregated ballast tanks anyway, sometimes even with freshwater. One possibility is the legal issues and political opposition in many water rich countries has effectively curbed not only large scale dedicated tanker trade but also other attempts at initiating water export. Another likely factor is the enormous investments made into desalination in the same period, progressively lowering costs and making it harder for other concepts to compete. Finally, it might simply be due to the fact that innovation in the conservative shipping industry usually comes slowly. A freshwater trade through return cargo would require cooperation between shipping companies and ports in the affected countries, as well as a certain level of involvement from national and regional authorities and IMO. For this to happen there must be sufficient demand present; in the Middle East this demand was effectively met by desalination and other land based projects.

Whatever the reason, it seems evident that a new study of the idea is justified. The developments in water distribution and demand as well as in shipping markets and technology over the past 20 years will have a huge impact on the question of whether or not it is viable today.

2 OIL TRADE AND TANKER CHARACTERISTICS

A key factor in determining the feasibility of FWBH are the patterns which govern oil trade, oil being the primary trade in a freshwater backhaul scheme. The location and capacity of oil terminals, the destination and volume of crude oil transported and the oil tanker age and operation profile all influence the feasibility of the secondary freshwater trade.

Major oil loading terminals of the world are located in the Persian Gulf, West Africa and South/Central America:

- Saudi Arabia - Ras Tanura: 6 million barrels/day(Largest offshore loading facility in the world), Ras al Jumayah: 3-3.5 million barrels/day, Yanbu: 4.5 million barrels/day(capacity not fully utilized) (44)
- Iran - Kharg Island: 5 million barrels/day, Lavan Island: 200,000 barrels/day
- Kuwait - Mina al Ahmadi
- Libya - Es Sider, Marsa el-Brega
- Nigeria - Lagos
- Angola - Cabinda
- Venezuela - Puerto de la Cruz, Amuay , Cardon

Oil (heavy and light) is the most traded commodity internationally both in terms of volume and value. In 2009 the world produced on an average 72 million barrels of crude oil per day, of which Middle East countries produced around 30% or 23 million barrels per day. Around 80% of the crude oil produced in the Middle East was traded by sea (880 million tons-2006 levels(45 p. 104)). The other great centers of oil production are Africa, South/Central America, USA and Russia, all of which use sea transportation in some magnitude to trade the produced oil. The major centers of consumption of petroleum products in 2009 were USA, Europe, China, Japan, India, Russia and Brazil, in that order(46). The major oil trading sea routes ranked by volume of trade (2008 levels)(45 p. 104) in the world are illustrated below:

- Middle East-Asia/Australia (426 million tons/year)
- Middle East-Japan (187 million tons/year)
- Caribbean-North America (178.6 million tons/year)
- Middle East- North America (119 million tons/year)
- West Africa-US (102 million tons/year)

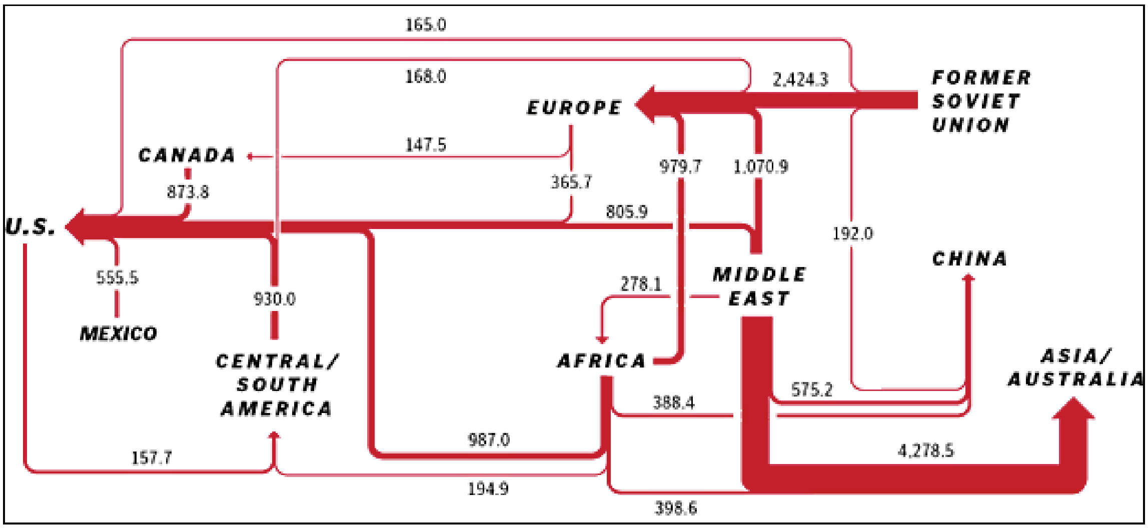

Figure 2-1: Total barrels of oil (in millions) traded in 2007(includes pipeline) Source: (102)

A total of 9,650 oil tankers, representing around 450 million tons of deadweight, were in service in late 2008 (47 p. 57), and these transported 1,888 million (45 p. 102) tons of oil by sea. Ship characteristics like size and speed used on a particular trade route are dependent largely on the voyage length, canal and port constraints. Around 35 % of the tanker fleet by tonnage consisted of VLCC and ULCC tankers with an average age of 9 years in 2008(45 p. VI). The tonnage share of VLCC and ULCC in the tanker fleet today has increased further due to a considerable volume of new buildings delivered by last quarter of 2009, reducing the average age of the tanker fleet even further. The majority of crude oil transported by sea from the Middle East is carried by Suezmax, VLCC and ULCC tankers towards Asia and North America.

Figure 2-2: Cross-section of an oil tanker with segregated ballast tanks (SBT)

The accelerated phasing out of all single hull tankers by 2010 according to the 2003 amendments to MARPOL 73/78 has lead to oil trade being carried out by mostly double hull tankers. Some single hull, double bottom tankers satisfying technical conditions laid down by MARPOL may be allowed by the administration to continue to operate even after 2010 until the vessel reaches 25 years of age. The number of such vessels is negligible compared to the total number of oil tankers in the world trade today. Single hull / single hull double bottom tankers can find their use for acting as floating storage and offloading unit for freshwater, discussed further in Chapter 3.3.4.2.

Based on the oil export statistics for the Middle East, and assuming a ballast volume of 30% of the deadweight on Suezmax, VLCC and ULCC tankers the total potential freshwater supply to Middle East would be around 200 million tons a year assuming all tankers with deadweight in the range of Suezmax tankers and higher backhaul freshwater. Even when the assumption is scaled down to 25% of the potential a yearly supply of 50 million tons of raw freshwater is feasible, or in other words sufficient freshwater for 60,000 people a year in terms of per capita consumption[7]. The quantities of freshwater provided by FWBH can thus only be an additional supplementary source of water for all the major oil exporting countries and cannot act as substitute for the existing water supplying facilities. FWBH can become a major source of freshwater for small islands or cities or for emergencies in case of natural calamities where normal methods of transportation by road/air are disrupted. The location of freshwater loading and unloading terminal in all cases is important and should be as close to the oil trading routes as possible. The major oil trading routes of the world have been illustrated in Figure 2-3 with some potential sources of freshwater close to the major oil routes already mentioned above.

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[7] Middle East per capita freshwater consumption estimated at 800 tons/person/year(11)

Figure 2-3: Major world oil trade route and potential freshwater loading and unloading ports

3 FWBH SYSTEM DESIGN

For an oil tanker to transport freshwater by its ballast spaces or cargo spaces on the return leg, the tanker operational profile may or may not undergo changes from the original trading patterns depending upon the location and type of loading/unloading terminals of freshwater.

A general system of freshwater trade by oil tanker return leg can have 4 different combinations in terms of oil and water loading and unloading terminals. This means that the number of ports involved can either be A) two -when freshwater is loaded and unloaded at the oil ports, B) three-when either loading or unloading of freshwater is done at a port different than the ports involved in the oil trade or C) four-when freshwater loading and unloading, both do not take place at the oil ports.

3.1 CONCEPT DEFINITION

For the purpose of this chapter we have divided the freshwater backhaul scheme into three major parts. The upstream design where the operation of capturing and loading of freshwater takes place, the midstream design covering the voyage between the upstream and downstream and including the vessel side modifications for accommodating freshwater ballast systems, and the downstream design which include the operation of unloading, treating and distributing the freshwater. For option A) the technical and infrastructure changes have to be done in such a way so as to accommodate the secondary trade without any interference with the primary oil trade i.e. the technical solutions to be devised should not add any time or any other constraint which does not already exist on the oil trade. Also some modifications may be required to the existing facilities on the oil terminals. For a FWBH system involving more than two ports of call, the time involved in loading and/or unloading freshwater becomes more critical. Thus such facilities are required to be of greater capacity and higher technical requirements in terms of loading/unloading rates to reduce the impact of deviation on the primary trade. Such a scenario also entails the oil tanker to carry sea-water ballast for a part of the voyage. The impact of carrying sea water ballast for a part of the voyage on freshwater and the occurrence of any harmful effects of the ballast water for short voyages should be researched.

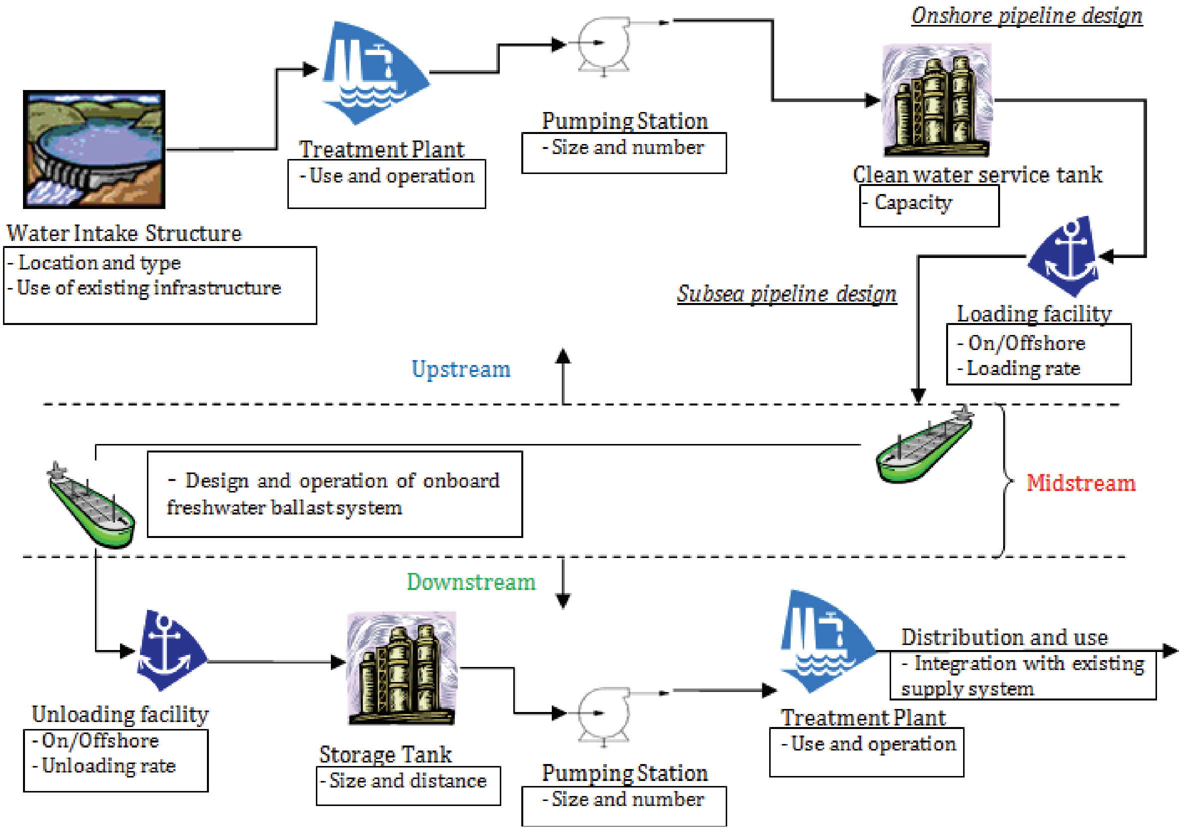


Figure 3-1: Complete FWBH system

The design and construction of all three parts fall under the responsibility of different parties and can only be possible if the concerned parties have some incentive to do so. The construction of the upstream facilities will be done if the technical design and operation of those facilities are economical and generate some profit for the water exporting country. A ship owner would primarily agree to do the technical modifications required to implement the FWBH scheme if it results in the owner earning some extra revenue while at the same time being exempted from following the ballast water convention. An exemption from following the ballast water convention for a large part of the return leg would mean lesser operational and maintenance workload on the crew and in general less administrative work for the owner. The saving in energy consumption and operational expenses due to elimination of ballast water treatment and exchange should be weighed in to analyze the feasibility and ease of use of FWBH in comparison with sea water ballast. The modifications of course have to be easy to implement and not interfere with the primary oil trade in any way. For the freshwater importing country the water should be available at a relatively cheaper cost and in reliable quantities. The reliability and quantity of the freshwater import become the two most important factors, which if assured can be the biggest incentive for the water importing country to go ahead in constructing the required infrastructure.

3.2 VESSEL SIDE MODIFICATIONS

The feasibility of a FWBH scheme depends upon the changes to the ballast and cargo lines of the vessel, which would integrate the FWBH seamlessly into the existing system. Major modification areas are the ballast pumping and piping arrangements and tank coating for ballast tanks. A general description of existing ballast and cargo arrangements have been made so as to understand why changes are required to the existing system. Installing a freshwater manifold on the deck which can load and unload the freshwater at desirable rates has to be implemented.

Placing the new manifolds as close as possible to crude oil loading and unloading manifolds should be a priority, so as to utilize the davits already onboard for handling the freshwater hoses.

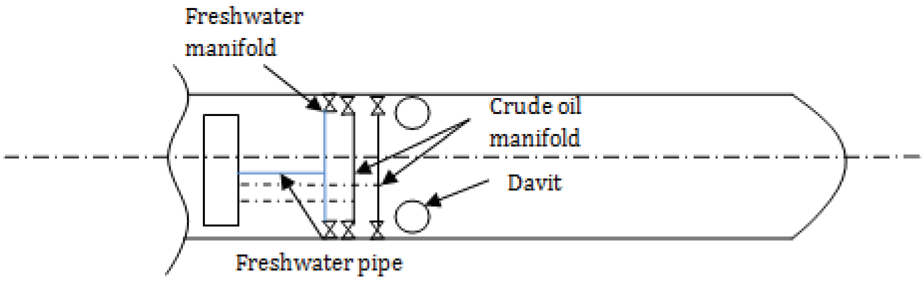


Figure 3-2: Freshwater manifold on deck

3.2.1 *BALLAST PUMPS CAPACITY*

Approximately 20% of the ships summer deadweight volume is required for satisfactory handling of ships while maneuvering in calm waters(48). This can increase in case of bad weather conditions. Also some port state/flag state rules require ships to carry more than the minimum ballast. An oil tanker usually has 25-30% of its total volume, reserved to carry ballast. As mentioned in the previous section these tanks which carry ballast are to be segregated. The ballast lines discharge the ballast overboard through an outlet in the hull which is under the lightship water line, having a discharge head of around 25-40 meters depending on the maximum draft of the vessel. A VLCC has ballast spaces capable of carrying around 40,000 to 100,000 DWT of seawater ballast. The time spent in port is very crucial from an economical point of view and has to be minimized as far as possible for oil tankers. VLCC`s in the Persian gulf spend around 20-24 hours loading crude oil. This includes time for mobilizing the loading operation and also bunkering, which gives an effective loading time of 10-12 hours. Assuming a similar time at the unloading port a cargo pumping capacity of around 15,000-20,000 m^3/hrs should be installed onboard to achieve a 12 hours loading time for a VLCC. The ballast pumping capacity in this scenario to achieve complete ballasting whilst unloading cargo or de-ballasting whilst loading cargo should have a minimum throughput in the range of 40,000 * 1.025/12 = 3,500 m^3/hr to 100,000 *1.025/20 = 8,500 m^3/hr. Pumps with a slightly higher capacity would be required, as the pumps run on decreased throughput when the ballast tanks near filling. Also in view of Ballast Water Management convention (BWM) classification rules may require to have a ballast pump of higher capacity than the minimum required. For example Bureau Veritas (BV) stipulates that all ships should be able to carry out the complete ballast water exchange of cargo holds, if used to carry ballast by one single ballast pump in twenty four hours(49). In view of operational and class requirements the ballast pumps on contemporary VLCCs happen to be anywhere from 3,500 to 10,000 m^3/hr. For the purpose of FWBH a discharge rate of 10,000 m^3/hr for the water carried in ballast tanks has been assumed to be satisfactory, thus eliminating any further need to increase the discharge capacity of the existing pumps.

A cargo pump is designed to pump out the cargo into storage tanks/receiving stations onshore situated at a distance. If ballast pumps are to be used to unload the freshwater carried in the ballast spaces the required discharge head of the ballast pumps comparison with the cargo pump head characteristics should be adequate. For calculating the required discharge head (H_p)

for transfer of freshwater to shore the important parameters to consider are the length of the pipeline to storage facilities (which determines the head loss due to friction), the depth of the vessel (so as to pump water from the deepest double bottom tanks) and the elevation if any of the storage tanks and shore pipelines.

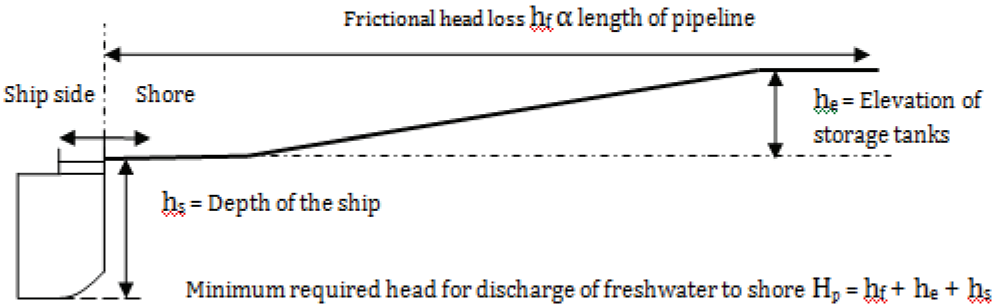


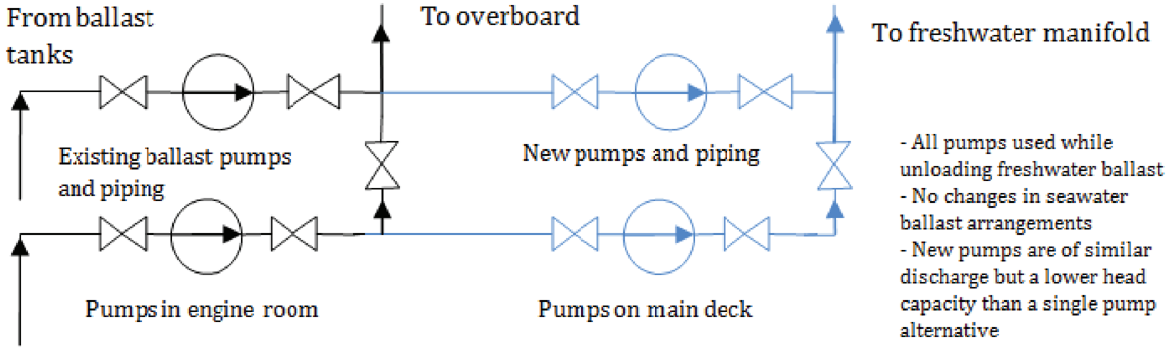
Figure 3-4: Minimum required head for freshwater ballast pumps

For a FWBH system we assume that the distance of shore based storage facilities from the ship and the pipeline contours on shore follow closely the cargo oil storage and piping system. Thus having a discharge head similar to a cargo pump should be adequate for transferring freshwater from ballast spaces to shore. Cargo pumps usually have a discharge head of around 100 to 150 meters to make them capable of pumping the cargo to storage areas on shore. A ballast pump with its usual throughput and an increase discharge head to 100-150 meters should be sufficient to transfer freshwater in ballast spaces to shore facilities in a combined oil loading and freshwater unloading scenario. The pumps will operate in a non-optimal region when ballasting/de-ballasting seawater which requires head of not more than 15-20 meters. Also, consideration would have to be made for not overflowing the ballast tanks and thus creating an over-pressure inside the tanks, which can result in structural failure of the tanks, while using pumps of high head capacity. Tank vents need to be re-designed for checking overpressure in the ballast tanks. Pumping capacity with higher throughput than 10,000 m^3/hr can be installed onboard to further reduce the loading and unloading time, but those pumping arrangement have not been included in further discussion as those arrangements would require a retrofit of the existing ballast pumps with possible changes to the thickness and diameter of the existing ballast lines. Our focus has been on analyzing and discussing technical options which would require certain levels of modifications be made to the oil tanker.

Thus increasing the discharge head of the ballast pumps to 100-150 meters is the only pump related change required to accommodate freshwater backhaul. This can be done by replacing the existing pumps or utilizing other options which result in a similar head and discharge capacity for unloading freshwater from ballast spaces.

3.2.1.1 Installing Intermediate Pumps

Installing another pump of the same discharge capacity in series with the existing ballast pumps is a solution to circumvent the installation of a single high capacity pump onboard. The high capacity pump would be inefficient to operate in case of carrying seawater ballast not needing higher head capacity. The intermediate pump can be placed on deck and will have a smaller required discharge head, reduced due to the head already imparted to the fluid by the existing ballast pump. The new pump is only used for unloading freshwater in tandem with the existing ballast water pump on board and thus can be of significantly lower capacity. This also increases the pumping efficiency for both the pumps as both pumps operate close to their design capacities when used. The diameter of the pipelines for the new pumping system is similar to the ballast water piping diameter. As these pipes will only handle freshwater no special inner coating is required for the new pipes.



- All pumps used while unloading freshwater ballast
- No changes in seawater ballast arrangements
- New pumps are of similar discharge but a lower head capacity than a single pump alternative

Figure 3-5: System arrangement with intermediate freshwater ballast pumps

3.2.1.2 Submersible Pumps

Installing pumps mounted inside ballast tanks for the sole purpose of freshwater discharge is one of the most flexible options; it also ensures fast operational time and gives rise to the least amount of modifications to the existing ballast system onboard. Each ballast tank can be installed with a submersible pump of sufficient capacity to facilitate the unloading of ballast tanks filled with freshwater within the time taken to load cargo oil. The ballast tanks on a VLCC have a capacity of around 10,000 MT (Appendix C)) (excluding the fore peak and aft peak tanks which are smaller in size and not used for FWBH in this analysis).

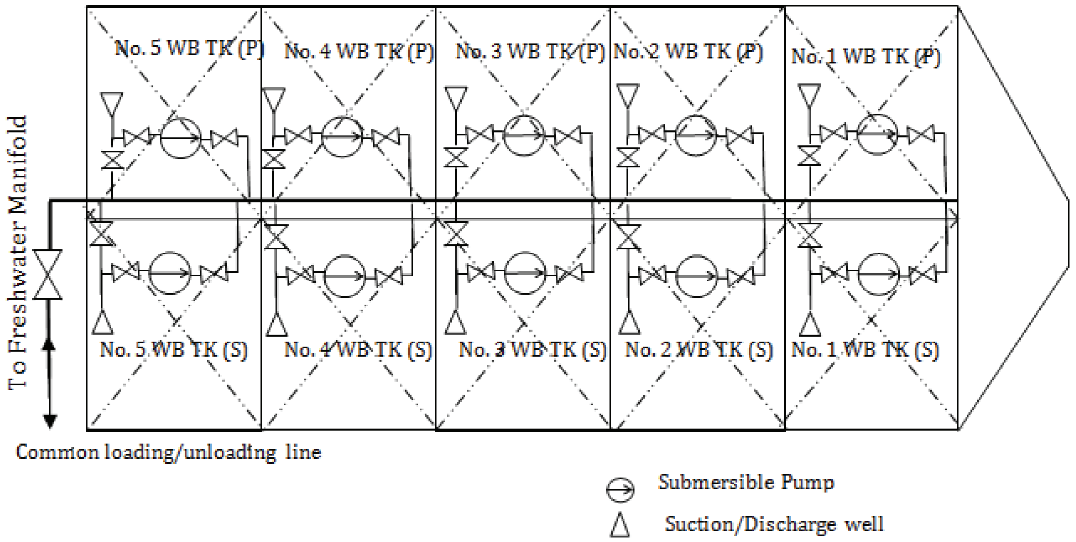


Figure 3-6: Pumping arrangement using submersible pumps

Having a submerged pump of around 1000 m^3/hrs and a discharge head of 100-150 meters for each ballast tank would result in an unloading time of around 10hours for the freshwater in the ballast tanks (referring to model VLCC). No changes have to be made to the existing ballast lines and pumps in this case. This combines seawater and freshwater ballast systems by keeping each piping arrangement isolated from the other and hence being easier to operate. Another advantage apart from ease of operation is that the freshwater carried in the ballast tanks would not be pumped using the ballast line arrangement, and thus preventing the freshwater from further increase in salinity by way of sediments and salts in the ballast lines.

3.2.2 *PIPING ARRANGEMENTS*

The use of the existing ballast line for pumping freshwater to shore requires installing new discharge lines from the pump to the deck, and construction of a freshwater manifold on deck. The existing cranes used for handling crude oil hoses from shore can be used to connect the shore line for freshwater to the ship`s freshwater manifold. A single manifold can be constructed on deck with 2-3 discharge lines to shore. Another alternative is to use portable hoses to load freshwater provided by the loading terminal or carried onboard. The hoses can be directly inserted in the ballast tanks through the hatch openings. A semi-permanent system can be installed by combining a fixed pipeline manifold for freshwater with a possibility to connect several hoses going in to the ballast tanks. The hoses can be used to fill multiple tanks at once and removed from deck after the loading operation has been completed.

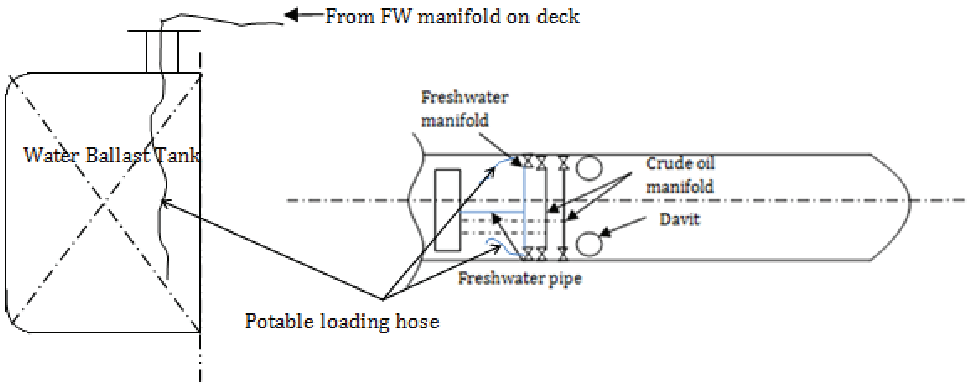


Figure 3-7: Loading arrangement using portable hoses

Portable hoses are the only option for loading freshwater in case of adopting the replacement of the existing ballast pump or use of an intermediate pump for unloading of the ballast tanks.

If the tanks are installed with dedicated submersible pumps, loading and unloading of freshwater ballast can be done by the same line and thus eliminating the need of portable hoses (Figure 3-6).

3.2.3 *TANK COATING*

The internal tank coatings used for corrosion inhibition may not be suitable for carrying freshwater ballast, especially for SBT due to leaching of the paint/internal lining. Depending on the type of paint used leaching can lead to increased levels of copper and lead in the water while causing some aesthetic issues like imparting odor, taste and color in the water. Using waterborne zinc silicate or a solvent free epoxy coating provides substantial help in inhibiting corrosion by seawater. Also coatings are almost always used in combination with sacrificial anodes placed inside the tanks. The combined effect of coating and protective anodes leads to elimination of corrosion to some extent inside the ballast tanks. Ballast tanks suffer the most when they are empty because of presence of large amounts of moisture and salt. Inerting the ballast tanks with gases which have been properly scrubbed and do not contain any amount of sulphur in them can be used as an effective corrosion inhibition solution. This eliminates the problem of finding an appropriate coating which can serve the dual purpose of protecting the ballast tanks from seawater while not deteriorating the quality of freshwater carried.

Use of polyurethane or glass reinforced plastic (GRP) coating can serve the purpose of corrosion inhibition when carrying sea-water ballast, whilst protecting the integrity of the freshwater carried (50).

For freshwater carried in cargo tanks no changes in coating should be required as the existing oil layer on the tanks acts as a barrier between the tank coating and the water inhibiting any corrosion which can be caused by carrying freshwater or any deterioration of the water by leaching.

Thus inerting the ballast tanks or use of polyurethane/GRP coating gives an ideal coating solution for the ballast tanks. Use of existing epoxy or zinc based coatings can be done without any changes after further analysis prove that the water carried in such tanks does not inherit toxic/harmful chemicals for long durations of haulage through leaching.

3.3 PORT SIDE DESIGN

Freshwater trade by tankers, barges and dedicated water carriers has been done before to supply water in emergency situations and to supplement the current supply or even as the major source of freshwater for small islands and countries. As mentioned in chapter 1.3.2, the island of Nauru received as much as one third of its water supplies as a return cargo from tankers supplying phosphate to Australia, Fiji and New Zealand (51). Barges were used to transport water to Antigua in 1982-83 when more 90,000 m^3 of water was supplied during drought conditions. Turkey has been supplying freshwater to Turkish Cyprus by tankers and had talks with Israel for a possibility of supplying freshwater by tankers from Turkey`s Manavgat river to the port of Ashkelon in Israel (presently Ashkelon SWRO plant provides for 5-6% of Israel`s freshwater requirement with a output of 111 million m^3 in 2008(52)). Turkey has developed the upstream infrastructure which includes construction of water intake and treatment plant which uses an offshore buoy to load water on ocean carriers for supply in the Mediterranean region (Israel, Jordan, Tunisia, Malta)(53).

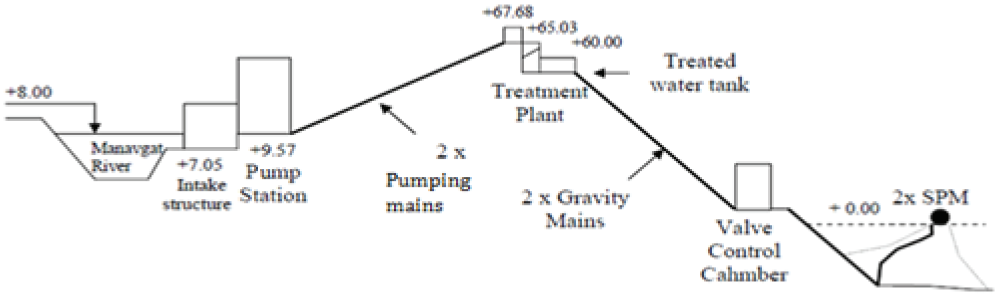


Figure 3-8: Upstream diagram of Manavgat River water supply project Source: (53 p. 4)

The supply side infrastructure for freshwater trade involves a catchment/storage area with a pumping station near the freshwater terminal and an appropriate method of loading into the oil tankers. The size and draught of large crude oil carriers can impose a constraint on their movement and ability to berth at piers. In places where it is not feasible to use fixed land based facilities due to draft constraints or other land based limitations for load tankers with freshwater, different offshore loading facilities can be developed. These are single-point moorings (SPM) or another tanker/barge used as an offshore unloading unit. Different components of a freshwater supplying terminal are (broadly)(53 p. 177):

1) Water intake structure
2) Pumping stations
3) Treatment plant (For removal of sediments from river water, which may not always be necessary depending upon the water quality of the river/basin)
4) Booster pumps if required to reduce the pipeline diameter to economic levels
5) Reservoir on the port/water terminal
6) Onshore/subsea pipelines
7) Offshore/onshore loading facility
    (i) Combined oil unloading and water loading berths
    (ii) Single point mooring
    (iii) Loading from barge/pontoon

The downstream components in the unloading system are similar to the upstream requirements with the addition of a treatment plant which can provide the final freshwater of required quality to the point of distribution/consumption. Separate/duplicate unloading lines may be required for unloading water mixed with oil carried in cargo tanks and water carried in ballast tanks in case the unloading port is expected to receive freshwater from both these schemes.

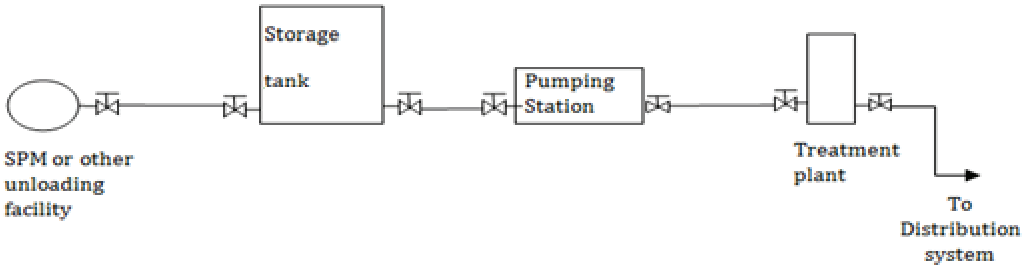


Figure 3-9: Downstream infrastructure for FWBH

To initiate FWBH potential sources of freshwater on the major oil trading routes should be identified. These sources should be reliable and at the same time not lead to a big deviation from the current oil trading patterns.

The infrastructure to collect, store and load freshwater for FWBH in quantities of 70,000 to 150,000 DWT for VLCCs and ULCCs are not in existence at the potential freshwater ports. Some research has already been done in development of delivery system of freshwater for ballast purposes specially during the 1980`s when new rules for SBT for oil tankers were just introduced and the tanker market was experiencing an excess in supply tonnage. Also there have been studies which propose facilities for construction of freshwater port for the purpose of dedicated freshwater trade, for example in Turkey and Australia (31),(53). In this section we try to draw upon the information from previous studies and research and present different options and technical aspects required for a freshwater loading/unloading facility.

3.3.1 Water Intake Structure and Supply System

The type and size of the intake structure is determined by local geographical and hydrological conditions. Utilizing present infrastructure by way of developing/modifying existing facilities presents a cost effective and quick solution. For example an existing reservoir of a hydroelectricity plant or a dam built for irrigation which is sufficient in size to store excess water can be used to store water for FWBH, with a pumping station built downstream to transfer the water offshore or to a loading terminal. The same can be done by capturing the outflow from a hydroelectricity plant into a reservoir. The location of the intake structure also has an effect on the quality of water. If the intake structure is positioned sufficiently upstream before the water from the river is diverted in to dams or reservoirs for agriculture or industrial use the water is less likely to be contaminated with fertilizers or industrial wastes/discharges. Determining the location of the intake structure becomes a balancing act between quality of water available from the source and the higher investment needed to capture water of higher quality. The greater investment is in the form of longer pipelines and thus greater pumping capacity and power requirements.

Depending upon the year round availability and flow rate of the water, building of a storage structure can in some cases be avoided altogether. Countries like Norway and Canada fall into this category as they already have an extensive dam and water storage network as the water is available perennially and also used to produce hydroelectricity (90% of power produced in Norway(54) and 60% in Canada(55)). But such regions wherein water is available throughout the year in quantities large enough to be utilized for export are rare. This introduces the need to construct dams/reservoirs to have a constant availability of freshwater year round. For regions with high precipitation and frequent floods, reservoirs can serve the dual purpose of mitigating harmful natural occurrences at the same time acting as a seasonal source of freshwater supply for freshwater trade.

For designing a water intake and supply system certain practical strategies must be kept in mind. These are (56 p. 132):

- Taking advantage of existing topography
- Selecting pipe diameters for least frictional losses in the system
- Operation of valves and pumps to be reduced to the minimum

The topography of the source of freshwater and the elevation of the intake reservoir determines the number and size of the pumping station required. Water supply and distribution system of different types used for supply of freshwater in cities can provide a rudimentary plan to design the freshwater supply system for FWBH(57).

3.3.1.1 High and Low Level Reservoir Systems

In places where the source of water has a natural elevation in relation to the port/water loading terminal the water from the source can be transported with minimal pumping requirements. Systems where reservoirs are about 30 meters above the distribution/consumption point are classified as High Level Reservoirs(57 p. 37). Such a gravity flow system is the most economical and reliable system as it reduces or in some cases eliminates the dependence on mechanical components and external power supply.

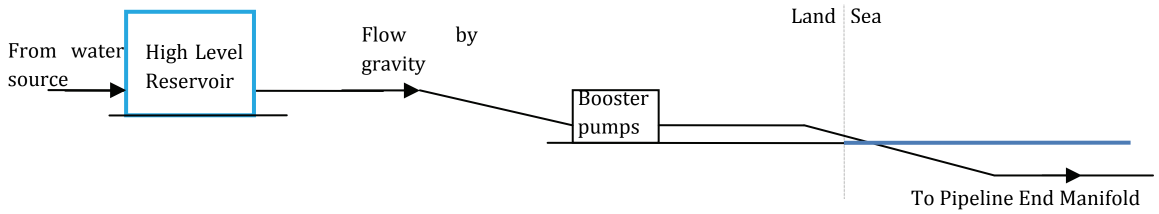


Figure 3-10: Schematic showing a high level reservoir system

In case the reservoir does not supply sufficient head by way of natural elevation, pumping stations with a reliable and continuous source of power have to be built.

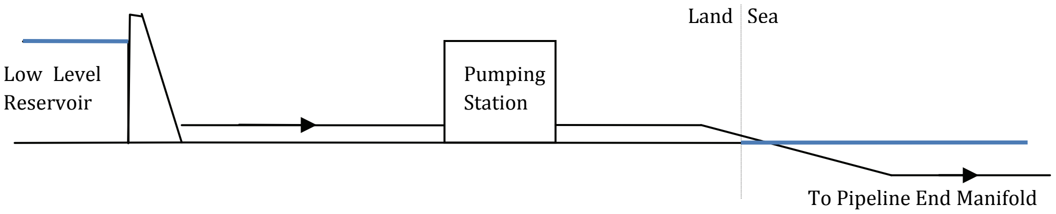


Figure 3-11: Schematic showing a low level reservoir system

Another pumping station between the water source and the intake structure may also be required. In such a case where the system necessitates installation of a pumping station between the source and the reservoir, the reservoir can be built at an elevation which is suitable to avoid constructing any more pumping stations downstream of the reservoir up to the loading platform/facility. Such a system has been built in Turkey on the river Manavgat. The water in this case is pumped to an elevation of 65 meters where there is a treatment facility and water reservoir. Downstream of the water tank the water flows by gravity up to the SPM`s, with a valve control chamber and pumping station for loading.

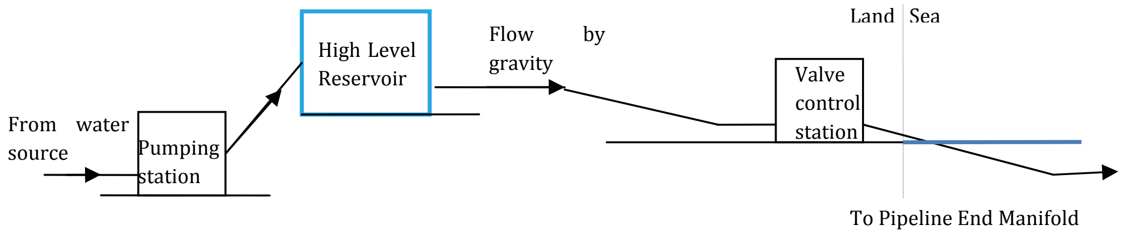


Figure 3-12: Schematic showing the Manavgat river project water supply system

3.3.1.2 Direct Pumping Scheme

In this scheme the pump operation schedule follows the freshwater demand by directly pumping water from source to the consumption/utilization point (56 p. 16). This eradicates the need of having a storage structure and any pressure requirements in the system can be reached. Additional pumping capacity may be required for accommodating future demand increases, which leads to increase in pump investment costs. This type of a system is complicated and proper selection of pump units is important for the sake of optimizing the power consumption. A constant and reliable source of power with an additional or back-up source maybe required as a precaution. Operation and maintenance of this system also become critical and thus large stores and spare parts have to be stocked.

3.3.2 *GENERAL PIPELINE SYSTEM DESIGN AND CHARACTERISTICS*

Design of pipelines and piping systems require broad knowledge covering a number of engineering disciplines like fluid mechanics, material technology and corrosion engineering. In addition various regulations, codes and specifications are to be adhered to for the fabrication and installation of pipelines. This section gives a general description of the various parameters to be looked into for initial design of a freshwater pipeline system on the freshwater loading and unloading terminals. The complete upstream (freshwater source to offshore loading buoy) and downstream facilities (offshore unloading buoy to water consumption point) will have several kilometers of overland and subsea pipelines. Good pipeline engineering and design becomes important for building an efficient and safe FWBH system. To ensure the longevity and integrity of the pipeline the following factors must be considered during the initial design.

I. **Route selection**: The selection of the shortest possible route is determined by various different environmental and technical factors which determine the final route selection of the land and subsea pipelines. The major factors have been described in brief below(58) (31) (59):
  a) Physical factors - A geological survey of the topography of an area gives information about surface gradient and profile, present wildlife if any and existing land/sea based structures. A typical pipeline route should avoid rocky areas to minimize rock blasting, archeological sites and important areas important for the local population. New land pipelines are usually built close to existing roadways for ease of access for maintenance and repairs. For a subsea pipe attention is given to avoiding areas subjected to sandwaves, subsea–ripples, very hard or very soft areas. Also the area should preferably have no existing pipelines to avoid damage and interference from the new pipeline construction. Areas close to ports usually have designated anchoring areas which are used by ships, but sometimes vessels anchor indiscriminately around port entrance. Such areas should be avoided or be clearly marked in case a pipeline is installed. Seabed close to ports undergo dredging and deepening operations which can be periodical to maintain the sea depth or to increase the seabed depth if a new port is to be constructed or to accommodate larger number of deep draft vessels. This can lead to extensive dredging during the lifetime of a pipeline and have an adverse impact on the pipeline support system. Pipelines are also seen as an intrusion to an existing fishing area.
  b) Environmental factors - Minimum disruption to areas rich in natural vegetation and wildlife should be a priority. The construction period should be scheduled at a suitable season so as to minimize damage to wildlife especially for the construction of the subsea pipelines.

II. **Physical attributes** (59 p. B.19): Pipe thickness, diameter, method of joining the pipes, pipe fittings layout and dimension are all the parameters which come under the physical attributes of the pipe. Different codes and standards are already laid out for different piping components and the pipe thickness and diameter for a freshwater pipeline. The American Water Works Association (AWWA) is the body which publishes standards followed internationally for pipelines and components used in water treatment and distribution systems

III. **Loading and service conditions**(59 p. B.20): Different forces and loads on the pipeline generated internally or externally comprise the loading condition of the pipeline, and the combination of one or more of these loads acting together on the pipeline during its operation is known as the service condition of the pipeline. Internal pressure, forces and moments on the pipeline due to its weight, temperature variations causing thermal stresses, wind and other environmental loads all act on a typical pipeline system. The freshwater pipeline is to be designed to withstand these loads and their combined effect. Service conditions can be specified by particular codes and standards. *AWWA standard C150-Thickenss design for ductile iron pipe* specifies the service conditions for ductile iron pipes by listing down various values for earth and truck loads with the depth of cover under land. The final thickness of the pipeline is taken to be the greater of the thickness found to resist hoop stress due to internal pressure and the thickness found by considering the earth and truck loads. The final thickness is obtained by adding the casting and service allowances to the pipeline. The casting allowance is included to account for the slight variations resulting from the casting process done during the making of the pipe. The service allowance accounts for the scratches and abrasions resulting from the handling of the pipe and provides an additional factor of safety.

IV. **Environmental factors**: Operating conditions which lead to deterioration of the pipeline up to an extent of structural failure are the important environmental factors of the system. Corrosion, erosion and physical damage are the common examples of such conditions. Corrosion rate depends on external and internal environment of the pipe. For freshwater pipes the oxygen content in water and the temperature of the water are important parameters governing corrosion rate.

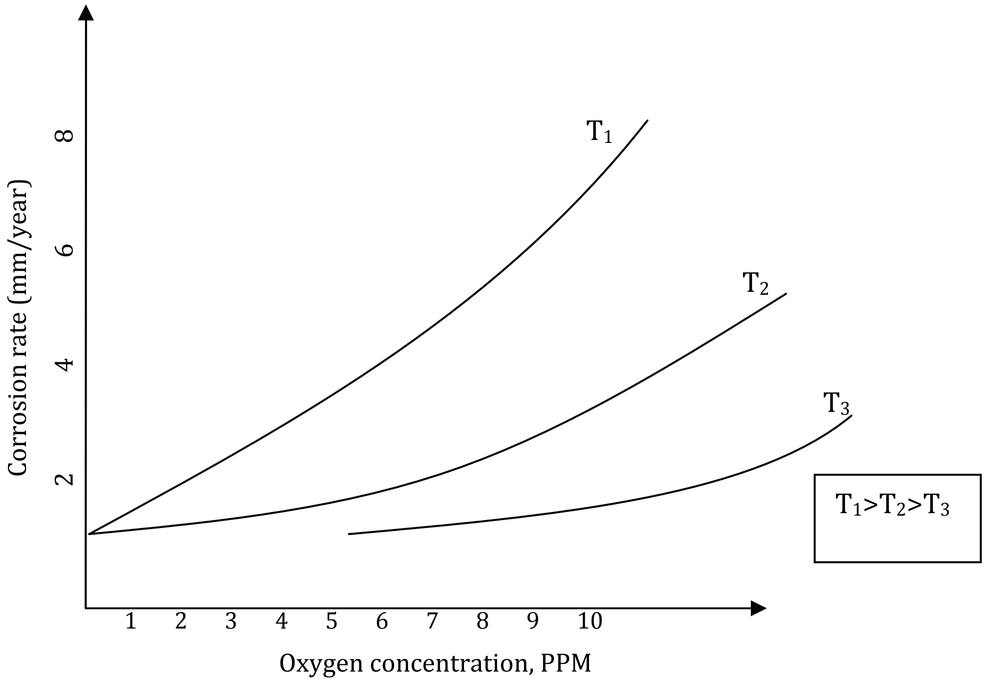


Figure 3-13: Effect of O_2 concentration and temp. on corrosion of low carbon steel pipes **Source(59)**

Corrosion and erosion can occur simultaneously on the water pipeline due to the flow velocity of the pipeline and is called flow assisted corrosion (FAC). FAC is the increase in localized corrosion rate due to the removal of soluble oxide layer called magnetite, which is formed when corrosion takes place on iron or steel pipes. The removal of magnetite layer can be due to high water velocity in the pipeline which results in increase in corrosion rate. When the flow rate of water is too low it can lead to microbial and organic growth in the pipelines. High flow velocities, turbulent and vortex flows also cause accelerated erosion due to abrasion and wear from suspended particles in the freshwater. Material selection becomes important to counter effects of corrosion and erosion. Cathodic protection, coatings and linings and selection of materials resistant to corrosion are some of the methods used to stop/restrict effects of environmental factors on the pipeline.

V. **Material**: There are various materials used for pipeline fabrication all of which can be broadly classified in to metallic and non-metallic materials. Further sub-classification can done as shown in the below figure.

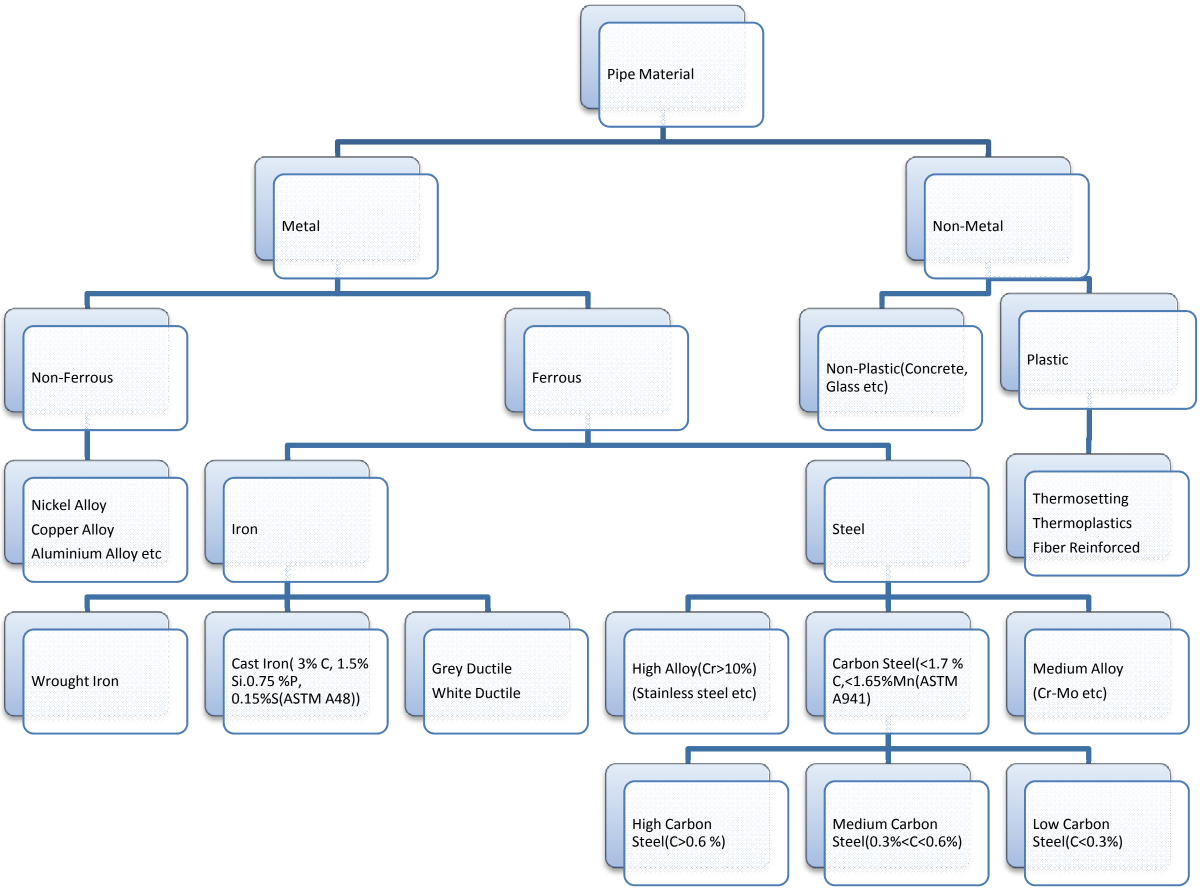


Figure 3-14 Overview of pipe materials Source: (60 pp. Figure 3-1)

Pipe materials normally used for water works systems are ductile iron (DI) steel, Polyethylene (PE), PVC (polyvinyl chloride), GRP (glass reinforced plastic), pre-stressed concrete, cylinder or non-cylinder, reinforced concrete cylinder, asbestos cement(61 p. 559). The major material related considerations for a piping system are strength of the material, toughness and corrosion resistance. The working temperature of the pipeline plays an important role for selecting the material. For freshwater pipelines the operating temperature is the ambient temperature and thus not classified under high temperature system. For ferrous materials the ductility and strength change with working temperature leading to the definition of transition temperature which is temperature above which steel behaves in a ductile manner and below which it behaves like a brittle material. Hence using steel with good ductility at low temperatures or in other words a low transition temperature would be suitable for freshwater pipeline system. One of the issues related to non-metallic pipelines is permeation of volatile organic content from the soil in to the water. Formation of vinyl chloride in the pipe is another issue associated with PVC pipes which can cause direct deterioration of the water being pumped(62). For subsea pipelines the study plans to use steel pipes made of X65 steel with 1200 mm diameter. The methodology to calculate the optimum diameter of a pipeline has been discussed in section XX. The subsea pipelines are protected by a sacrificial anode method, while having an internal coating of epoxy and polyurethane. The external coating of the pipeline is in the form of weighted concrete to provide stability to the pipeline.

VI. **Combining hydraulic and engineering design**: Selecting values for pipe diameter, thickness and the corresponding capacity requirement for pumping stations is the outcome of finding a balance between higher investment costs for larger diameter of pipes while at the same time greater savings from reduced frictional losses in pipeline due to larger diameters leading to lesser pumping requirements and power. Also making decisions about selecting pump manufacturers which also supply standardized valves and fitting for the complete system, selecting material and machinery based on ease of availability and maintenance and selecting other hydraulic parameters like diameter and thickness of the pipe while keeping in mind that this selection would conform with the available installation technologies can lead to reducing costs and increasing reliability of the system.

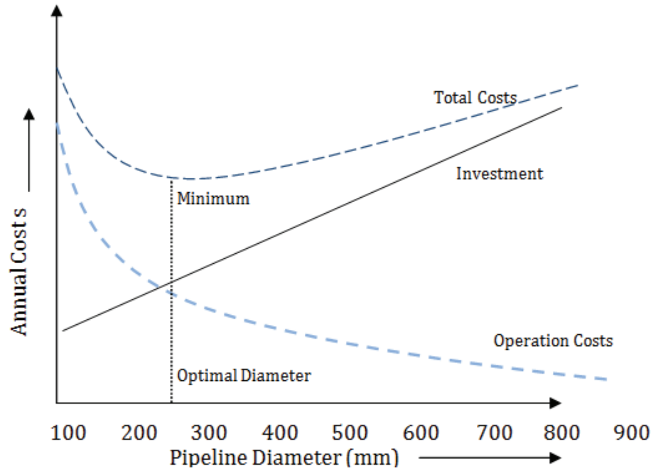


Figure 3-15 Main pipe diameter selection **Source:(55)**

VII. **Use of codes and standards in a piping system**(59 p. B.21): Codes provide design rules and criteria to be considered for design of a piping system. Compliance to a specific code is usually a pre-requisite of the regulatory or the insurance agency to ensure safety and durability of the pipeline. Some of the codes which are widely followed for selection, fabrication and testing of pipelines are published by American Society of Mechanical Engineers (ASME), API (American Petroleum Institute) and International Standards Organization (ISO). National rules are specifications are also used in conjunction with international rules. Standards on the other hand provide specific design criteria and rules for individual components. Following a particular standard ensures that the components manufactured by different suppliers are interchangeable and also the components have a minimum performance criterion. Standards are usually laid down by the owner/purchaser.

3.3.3 Design of a Up/Down Stream Supply System

As mentioned previously the design of the water supply and delivery system on the freshwater loading and unloading terminals can be divided into hydraulic design and engineering design. Hydraulic design includes pipeline sizing, the required reservoir volume and pumping capacity in the system. Engineering design deals with making decisions regarding selection and choice of components, materials, construction and installation procedures (56 p. 163) based on technical and financial grounds.

3.3.3.1 Hydraulic and Engineering Design

The determination of the diameter of the pipeline to be used and the pumping capacity of the system are inter-related such that increasing one of parameters would reduce the capacity of the other. Increase pipe diameters lead to reduction in the design pumping capacity due to less head loss in the pipelines. Similarly the size of the reservoir required is dependent to some extent the maximum pumping capacity of the system. The larger the pumping capacity the lesser time needed to fill the reservoir for a fixed demand and hence less buffer volume or reservoir volume required to satisfy a given demand profile.

The hydraulic sizing of the pipeline includes two independent design functions: fluid flow design and pressure integrity design (59 p. B.59). The fluid flow design leads to determination of minimum inside diameter of the pipeline and the pressure integrity design to the minimum wall thickness of the pipeline.

3.3.3.2 Fluid Flow Design

The goal of fluid flow design is to find the inside diameter of a pipeline for the design flow rate while maintaining pressure drop and fluid velocity in the system within realistic levels.

To determine the internal diameter of a system an iterative process is used which gives an optimal solution for least operation cost and greatest reliability for the complete system. This section describes the basic methodology involved in calculating pipeline diameter.

Design parameters like length of the pipeline *(l)*, required flow rate *(Q)* and density of the fluid (ρ) and the kinematic viscosity (v) are known/decided and act as input for further calculations. An arbitrary diameter is selected for the first iteration and then by using Bernoulli`s equation to calculate pressure difference between two points on a stream line by including frictional and minor losses (which include losses due to bends, branches, valves and other fittings) pressure losses between the start and end point of the pipeline are found. The frictional losses are calculated by using the Darcy-Weibash equation and Moody Chart to find the frictional factor.

Parameter	Unit	Remarks
Required Flow rate	Q (m^3/sec)	As high as possible
Total length of the pipeline	L (m)	From route selection
Density	ρ (kg/m^3)	Fixed(1000kg/mm^3)
Dynamic Viscosity	μ (N.s/mm^2)	Fixed
Kinematic Viscosity	v (mm^2/sec)	*Fixed(1mm^2/sec at 20^0C)*
Absolute pipe roughness	*ϵ(mm^{-6})*	*Depends on pipe material(45 microns for commercial steel)*
Diameter of the pipe	*D(mm)*	*To be found iteratively*
Velocity of fluid in pipe	*V(m/sec)*	$V=Q/A$; *where* $A = \pi D^2/4$
Reynolds's Number	*Re*	$Re=\rho.V.L/ \mu$
Frictional factor	*f*	*From Moody chart, Reynolds number and relative roughness*

		required
Darcy-Weibash Equation	$h_f = f\,(L / D) \times (V^2 / 2g)$	Calculates the head loss from flow through the pipeline due to friction.

Table 3.1 Input parameters for finding diameter of a pipeline

The pipe diameter is gradually increased until an acceptable value for pressure loss in the system is reached, while having reasonable flow velocity in the pipelines. A flow velocity of up to 2.1 m/sec is considered reasonable for freshwater flowing through a pipe(59 p. B.60). The pressure loss value combined with the elevation required and the required output pressure in turn gives an initial estimation for the capacity and size of the pumps to be used in the pumping stations. As mentioned earlier the final selection of the pipe diameter is done for the value which gives the least operating and investment cost. Different pipe materials like carbon steel, galvanised iron, concrete and PVC are taken in to account by changing the value for the relative roughness for the pipe and hence the frictional factor.

3.3.3.3 Pressure Integrity Design

The aim of pressure integrity design is to calculate the minimum nominal thickness of the pipeline and determine the pressure rating of the various fittings and components to be used on the pipeline. As mentioned on page 33 the final thickness of the pipeline would incorporate effects of corrosion and tolerance for manufacturing uncertainties.

$t = (t_o + b + c)\, m$ (63)

where,

t= minimum required wall thickness (mm)

t_o = minimum thickness of pipeline considering internal pressure only

b = allowance for bending

c= corrosion allowance

m = coefficient to account for negative manufacturing tolerance

Calculating t_o

The different stresses acting in a pipe of diameter (D) filled with fluid at a pressure (P) are hoop stress (h), longitudinal stress (l) and radial stress(r).

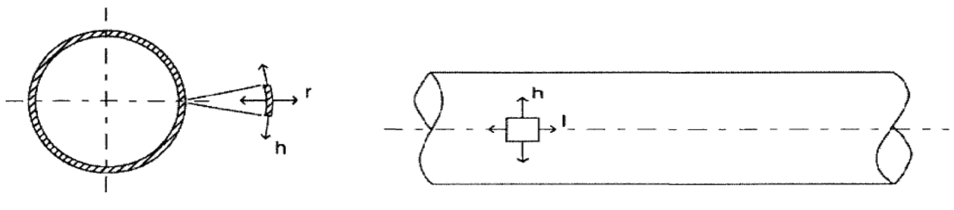


Figure 3-16: Stress in a pipe **Source : (60 pp. Figure 4-1)**

The hoop stress which is the largest stress in the pipe is given by:

$\sigma_h = PD/2t_o$

Where

σ_h = Hoop stress (N/mm^2)

t_o = thickness of the pipe (mm)

P = internal design pressure

D= outer diameter of pipe

The hoop stress in the pipeline has to be limited to a certain allowable stress (S_a). S_a is usually mentioned as a percentage of the specified minimum yield stress of the material of the pipeline (S_y)(60 p. 4.1.2).

$S_a = S_y.F.\ E.\ T$
F = Location design factor (Table 3.2)
E =Weld joint factor
T= temperature de-rating factor

Material	Pipe Class	E
ASTM A 53, A106	Seamless	1.0
ASTM A 53	ERW	1.0
ASTM A53	Furnace Butt Welded	0.6
ASTM A 134	Electric Fusion Arc Welded	0.8
ASTM A 135	Electric Resistance Welded	1.0
API 5L	Seamless	1.0
API 5L	Submerged Arc Welded or ERW	1.0
API 5L	Furnance Butt Welded	0.6

Table 3.2 Examples of Longitudinal weld joint factors [ASME 31.8]

Location	F
Class 1 Div. 1 : Deserts, farm land, sparsely populated, etc.	0.8
Class 1 Div.2: Class 1, with line tested to 110% design	0.72
Class 2: Industrial areas, town fringes, ranch, etc.	0.6
Class 3: Suburban housing, shopping centres, etc	0.5
Class 4: Multi-storey buildings, heavy traffic, etc	0.4

Table 3.3 Location Design Factor F [ASME B31 . 8]

Temperature(^{o}F)/(^{o}C)	T
250 or less/121 or less	1.0
300/148.8	0.967
350/176.6	0.933
400/204.4	0.9
450/232.2	0.867

Table 3.4 Temperature derating factor [B31.8]

Referring to the relevant regulation for the maximum allowable permissible stress the minimum pipe thickness can be found for the onshore water piping. A corrosion allowance is added based on the environmental conditions of the pipeline and the service for which the pipeline is used. Corrosion through the lifetime of the pipe to a certain degree a simple and easy parameter to predict; to avoid complexity in predicting corrosion accurately the material selection becomes important and should be done by using the past experiences or referring to standards like NACE, API which provide corrosion rates for specific material-environment combinations.(60 p. 20.12).

Different corrosion prevention techniques include lining of the internal diameter of the pipe, coating the outer diameter and impressed current cathode protection using a sacrificial anode (ICCP). The properties of the coating should be compatible with the material on which it is used. Also the environmental conditions while applying coatings on the pipeline play an important role in the effectiveness of the coating itself. Wind, dust and humidity conditions and proper surface treatment of the area to be coated is important to achieve the desired properties of the coating. The American Society of Testing and Materials (ASTM) publish properties like strength, hardness, water absorption and resistance to acids and alkalites and many others for different coatings. These guidelines are helpful in deciding upon the coating and lining to be used for a given environmental condition and material of the pipe. Some standard coatings for different pipe materials have been listed below.

Pipe Material	Type of Coating	Type of lining (for large diameter pipes)
Ductile Iron Pipe	Spray coating with Zinc followed by coating of bitumen paint(61 p. 564)	Mortar and concrete lining
Steel pipes	Bitumen sheathing; fusion bonded epoxy; three-layer polyethylene (PE) and paints.	Mortar and concrete lining

Table 3.5: Protective coatings for ductile iron and steel water pipes

Its is beneficial from a initial design perspective to know the selected pipeline diameters and corrosion inhibition systems employed on similar projects and studies done for FWBH piping elsewhere in the world. The selected diameter during the initial conceptual analysis in Australia and installed in Turkey for setting up a freshwater loading system was 1200 mm(31)(53). The conceptual study proposed building the pipelines with epoxy coated steel for land and using X65 steel(X65 is a higher strength, tough and weldable steel- API 5L: Specification for land pipes standard) of 12 mm wall thickness for sub-sea pipelines. The corrosion inhibition methods proposed were using impressed current cathode protection system in addition to the insulating epoxy coating for land pipes. The power station for cathodic protection would coincide with the pumping stations. For sub-sea pipelines using sacrificial anodes of sufficient size placed at optimum distances in addition to internal epoxy coating and external polyurethane and weighted concrete coating which also provides stability and support to the pipeline can be used.

Pipe parameter	Value/Selected option
Number of pipes	2
Diameter of Pipes	1200 mm
Wall Thickness	12 mm(gravity main)/8.8 mm (pumping main)
Length of Pipeline	10,000m(gravity main)/1057m (pumping main)
Type of Pipes	Spiral Welded Steel Pipe
Inner Coating of Pipes	Cement Added Concrete
Outer Coating of Pipes	Polyurethane

Table 3.6: Initial onshore pipeline specifications in Kimberley river project Source: (31)

3.3.3.4 Pumping Station

Proper selection of pump characteristics like type, size, number and mode of operation is a vital factor in creating an efficient, low maintenance and economic system for water transport. Before selecting the different characteristics of a pump certain input/design parameters should be known or decided. To begin with it is essential to know the minimum required pump discharge head and the desired flow velocity in the pipelines. The desired pumping head can be divided into *static* and *dynamic* head. The required *static head* of the pump is the head which is independent of the flow of the pump.

$$H_{st} = \frac{p_{end}}{\rho g} \pm \Delta Z$$

Where p_{end} = Pressure at the end of the pipeline
ΔZ = elevation between supply and end point

The dynamic head is the head loss due to flow characteristics of the pipe resulting from friction and other minor losses because of pipe fittings, curves and bends in the pipe. Selection of pipe line diameter has a direct effect on the dynamic head requirements of the pump.

The design theory behind the pumping capacity for up and downstream pumping station remains the same; we have used upstream pumping station as an example for discussing the design pumping characteristics. The determination of required flow rates in the pipeline in the upstream section can be divided into two segments separated by the water storage tank/reservoir. The first segment is the pipeline upstream of the water storage structure and the second segment is the pipeline downstream of the water reservoir up to the freshwater loading facility.

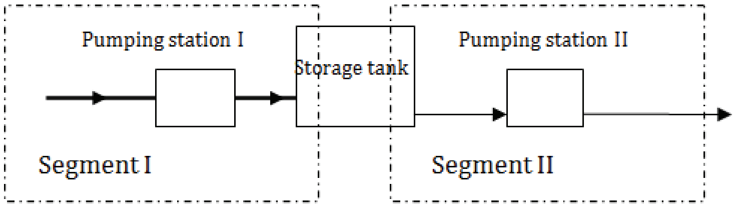


Figure 3-17: Different pipeline segments on shore

In segment II the pumps are used for loading of freshwater from the reservoir into tankers, the desired flow rate in this section of pipeline is the desired loading rate. The complexity of finding the flow rates in segment I where freshwater extraction takes place is slightly higher as it is related to the reservoir capacity and demand/abstraction rate from the reservoir.

The first step is to know the daily/monthly demand for freshwater backhaul by forecasting or using past statistics to assess the number of oil tankers calling a port in an area which will be interested in FWBH trade. Focusing on the months/time periods where the frequency of arrivals of oil tankers is the maximum, the minimum freshwater storage capacity required onshore between calls of two tankers can be calculated.

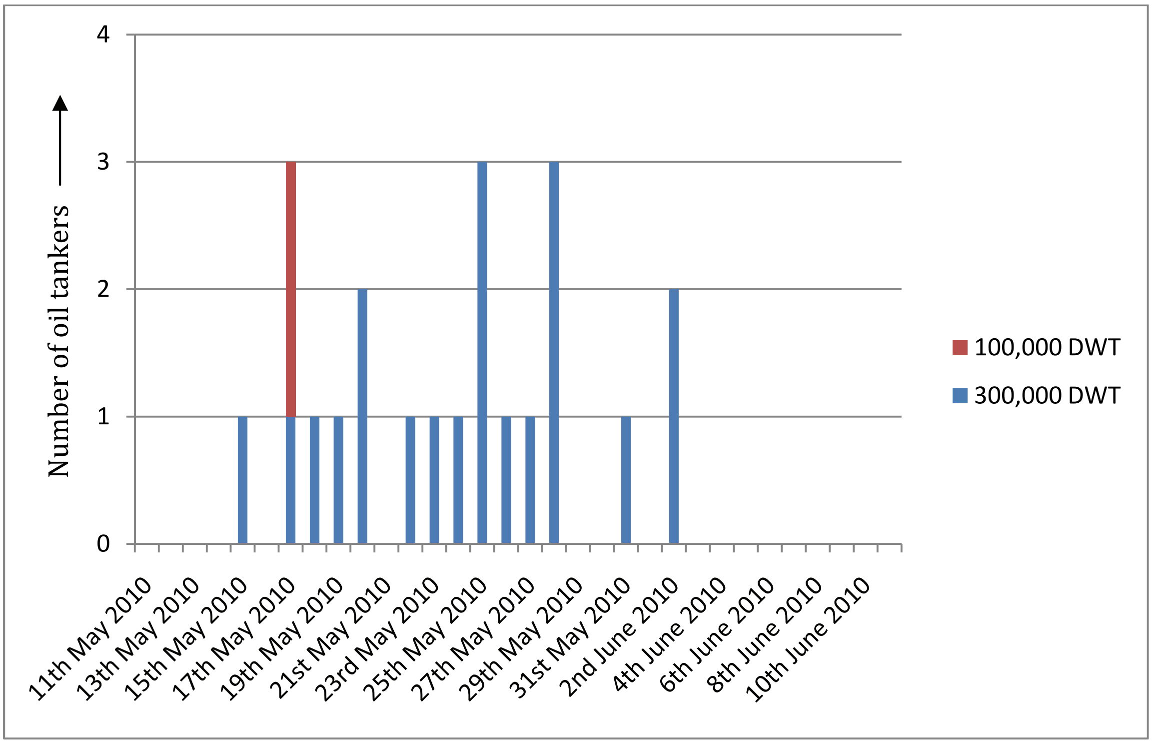


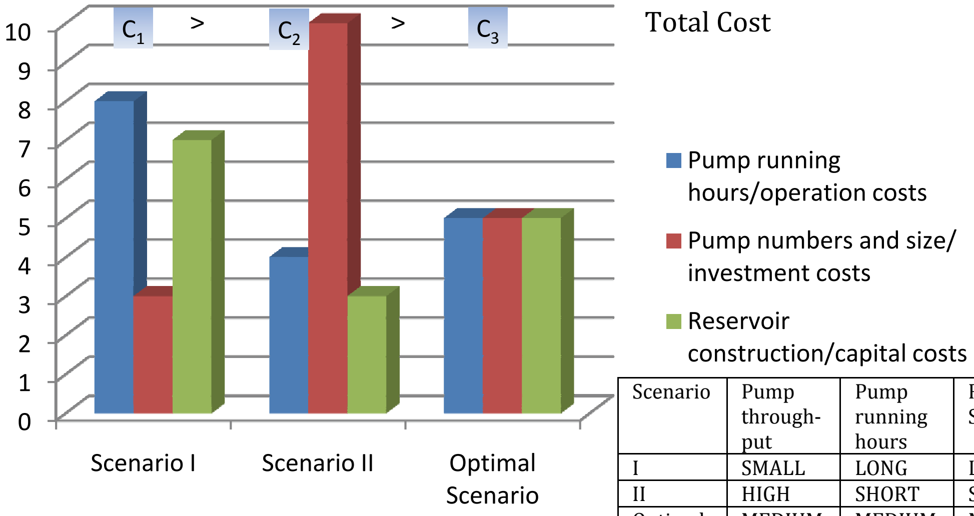
Figure 3-18: Frequency of crude oil tankers expected to depart Japan in a month Source:(64)

Figure 3-18 illustrates the number and size of the crude oil carriers which have/are expected to arrive at one of the various oil terminals in Japan which can accommodate VLCCs from 11thMay to 11th June. Let us also assume that there is a single freshwater loading terminal located at Yakushima Islands which is located south of the mainland and was being promoted as a freshwater terminal in the 1980s by the Japanese authorities (65). A loading rate of freshwater of around 10,000 m3/hr would result in a loading time of 12-14 hours for a 300,000 DWT tanker having ballast space volume of around 90-100,000 m3. This would mean a maximum of two tankers can be loaded with freshwater in a day from a single loading facility. Using simple simulation to maximize reservoir usage gives the minimum flow rate of freshwater in to the reservoir to be 62,258 m^3/day to satisfy the given demand of FWBH. A greater pumping rate would reduce the reservoir volume and the running hours of the pumping station.

Pumping capacity/day (m3/hrs)	Flow rate (m3/hrs)	Minimum reservoir volume (m3)	Days pump running in a month	Demand Satisfied
100,000	4,166	430,000	20	YES
50,000	2,083	930,000	31	NO
62,258	2,594	800,000	31	YES

Table 3.7: Reservoir volume calculations

The final choice of reservoir volume and pumping capacity lies in optimizing the pump and reservoir usage for the minimum total cost for the system. The reservoir construction costs do not change drastically with large increase or decrease in the reservoir volume as compared to the capital costs for higher capacity pumps and the related fittings and valves.



Scenario	Pump through-put	Pump running hours	Reservoir Size
I	SMALL	LONG	LARGE
II	HIGH	SHORT	SMALL
Optimal	MEDIUM	MEDIUM	MEDIUM

Figure 3-19: Graph depicting basis for engineering decisions

After the flowrate and the reservoir size has been decided upon the final selection of the pump can be done. The performance parameters which are normally used to describe pump parameters are :

- Flow rate (Q) and Total head (H)
- Power consumption and efficiency of pump
- Net positive suction head (NPSH) at inlet

The change in flow rate of the pump changes all the other performance parameters, and at a certain flow rate the pump efficiency is maxed at what is called the best efficiency point (BEP). The point of intersection of the requiered head H_a with the head generated by the pump H is the operation point of the pump and should coincide with the maximum efficiency of the pump. For the purpose of FWBH two separate pumping stations may be required. One which supplies water to the reservoir from the source and the other which loads water into the oil tankers. Both pumping stations have a high flow and medium to high head requirements which implies that only centrifugal pumps can be considered for use. The variation in the demand for FWBH system can be extremely wide-ranging as it is connected with the variation and volatility of the oil market. To accommodate this a variable discharge pump should be installed in combination with a fixed discharge pump of lower capacity. The purpose of the fixed discharge pump is to have additional pumping capacity in times of exceptionally high demands, which has a fair probability of happening due to the volatility in the oil trade. For the desired design requirement multi-stage radial pumps are most suitable. The increase in the cost of the multi-stage pump in comparison with a single stage pump pays-off quickly for large pumping stations due to higher volumetric and mechanical efficiencies leading to lower power consumption.

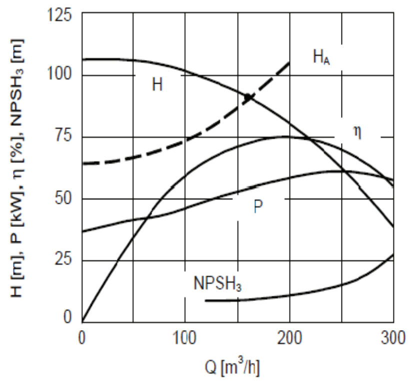


Table 3.8: Example of best efficiency point (BEP) of a pump **Source: (66 p. 47)**

Other criteria which are important and have an effect on the pump selection for minimum energy and maintenance costs are:

- Rated flow Q_r: the flow rate at which the pump is most often operated is the rated flow rate of the pump. The high flow rates make it furthermore important to operate pumps close to BEP for low energy costs and wear and tear of the pump
- Stability of H vs. Q curve: the head of the pump should reduce steadily with the increase in the flow rate of the pump. This is due to the fact that a H-Q curve which remains flat over a large area induces excessive vibrations in the pipeline.
- Operation at maximum flow rate: The pumps for FWBH would operate close to the maximum flow rates throughout its life cycle. Thus making sure that sufficient NPSH is available is important to avoid cavitation and the need for expensive impellers to deal with this effect.
- Uniform approach flow: While trying to keep the pumps compact and cheap, designers can sometimes develop systems that are difficult to operate. Common problems include increase in vibration and noise at the expense of reduced efficiency of the pump. Uniform inlet velocity to the eye of the impeller is desired to avoid cavitation and efficiency impairment. Installing flow straighteners, baffles and other relatively cheap structures can reduce or eliminate any operational difficulties.

3.3.4 LOADING AND UNLOADING FACILITY

The process and the machinery/equipment required for the unloading of freshwater from FWBH is technically similar to the loading process. Unloading freshwater carried by ballast water spaces and cargo tanks would require separate setup with similar infrastructure requirement. The water carried by cargo tanks needs to be separated of oil before further treatment or use. Using COW can reduce the oil content in the tanks if carrying raw freshwater to less than 15ppm. Using the cargo unloading system for unloading water carried in cargo tanks can lead to greater percentage of oil in the water while unloading. Further research is required in determining the quantity of oil in a COW tank if filled with water and unloaded using the cargo lines. Technically a separate pipeline leading to a treatment plant to purify water from oil would be the only additional requirement from a normal ballast water unloading system. The separated oil can be connected with the oil storage tanks already in the terminal used for loading oil. Different loading/unloading options with their pros and cons have been discussed further.

3.3.4.1 Independent Single Point Mooring System (SPM) installed offshore

Over the years tanker mooring systems have evolved to operate in higher sea states of around 5-6 m significant wave height (67). The transformation from having a floating hose connecting the buoy to the tanker for loading/unloading to a suspended hose acting as a catenary between the SPM and the tanker has resulted in reduction in difficulties and damages to the hose by currents. Another advantage is the free swivel characteristics of a SPM, bad weather and strong winds do not have as much impact on the loading operation as compared to an onshore fixed pier/berth. Also an offshore facility can accommodate deeper drafts of oil carriers without having to engage in costly and time consuming dredging for having a shore based terminal. The design and construction of the SPM should be done in such a way so as to include minimal distance of underwater piping, which is costly and presents a technical challenge to construct and maintain. Some studies like the Kimberley-Perth water project in Australia(31) and the Manavgat river project(53) in Turkey have proposed using SPM loading facilities. There are already two SPMs in place offshore of Manavgat in Turkey for the purpose of freshwater trade in the Middle east/Mediterranean region(68).

A fixed tower offshore connected to the underwater freshwater pipeline with a system allowing the tanker to weathervane is the simplest method of mooring a tanker(67 pp. 9-57). The fixed tower performs best when the water depth and wave heights are not too large. Also there is a high risk of widespread damage even in case of a minor collision from the tanker, due to the high bending moments acting on the tower with increase in water depth.

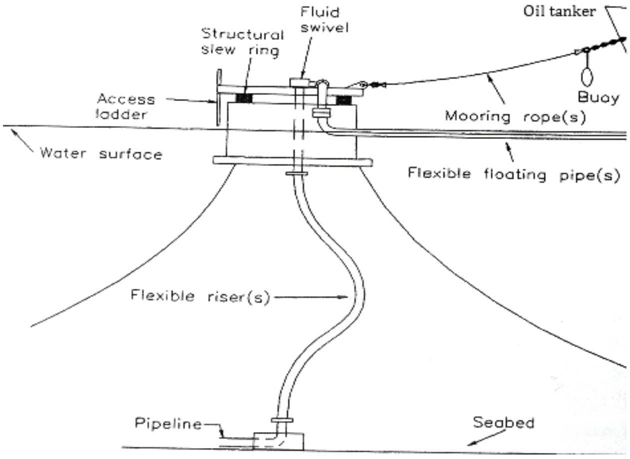


Figure 3-20: CALM Buoy **Source: (67)**

The most common SPM is CALM (Catenary Anchor Leg Mooring). The buoy is moored by chains or wires with a floating flexible hose for loading oil. The CALM comes in several different variations, but all have some common traits(68 p. viii);

1) A steel hull and six to eight mooring chains for mooring the structure to the seabed

2) A nylon or polypropylene hawser helps the tanker attach with the buoy. The hawser has some elasticity to absorb the mooring loads.

3) The underside of the buoy is connected to the Pipeline End Manifold (PLEM) with a flexible hose called the riser.

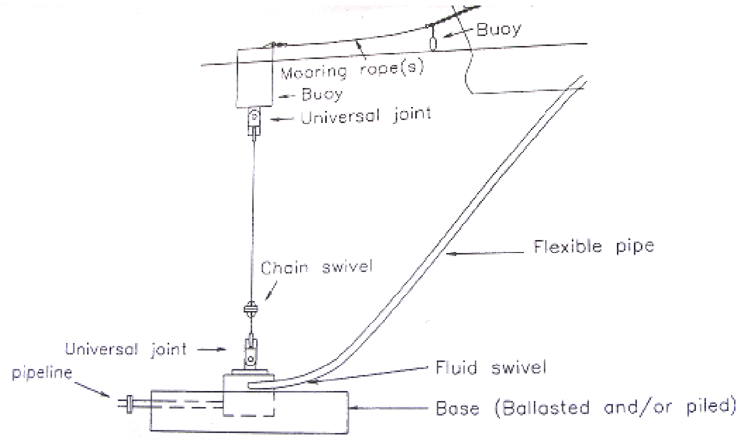


Figure 3-21: SALM Buoy

The drawback of CALM is that in case of a collision from the tanker the damage to the swivels can be extensive leading to the unit being out of action for considerable amounts of time. An alternative to CALM is the SALM or Single Anchor Leg Mooring wherein the collision damage can be limited. The SALM places the swivel safely underwater below the keel of the deepest tankers. Thus in case of a collision only the inexpensive structure of the buoy is affected, which can be easily repaired and replaced. The drawback of a SALM is that the maintenance of the underwater swivel becomes expensive and time consuming.

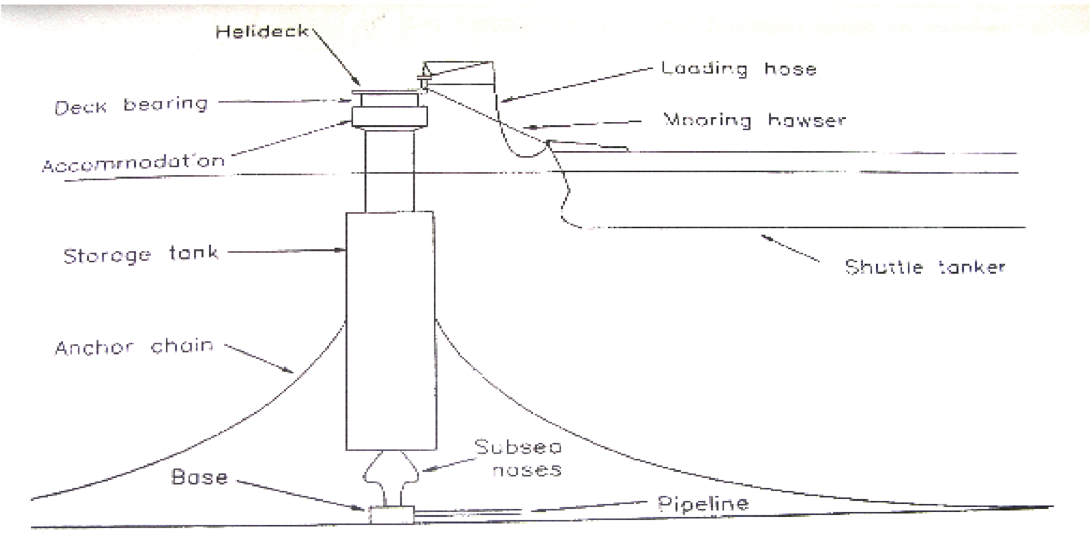


Figure 3-22: SPAR Buoy

A third SPM alternate is the Single Point Mooring and Reservoir (SPAR), which includes a underwater storage tank (Figure 3-22).

3.3.4.2 Loading from another tanker/barge anchored offshore

The use of one or more large tankers or barges to act as floating loading units anchored offshore or within the oil unloading terminal can be a flexible and easy to implement alternative.

A tanker or barge can be anchored offshore to receive the freshwater carried in the ballast spaces of returning oil tankers. If a newbuilding is utilized for this purpose the complexity of construction and size of propulsion machinery can be significantly smaller than when converting a normal seagoing tanker.

In case of simultaneous oil unloading and freshwater loading into ballast spaces, the barge/tankers should be provided with high discharge capacity pumps similar to the oil tankers ballast pumps. The system of loading freshwater should be made reliable and a low risk operation as it is vital that the freshwater transfer from the barge/another tanker does not interfere with the oil loading operation. A tanker can also be used as an offshore loading unit thus providing a simple and flexible loading option.

3.3.4.3 HiLoad Technology

A relatively new technology developed by Remora ASA, Norway which is under the last phase of sea trials and commissioning is called HiLoad. This system can be used for mooring and loading of tankers under harsher environmental conditions and also shallow water depths. The system consists of friction fenders which are mounted on a floating loading unit shaped as a fork lift. HiLoad attaches itself to the tanker with a force much higher than a normal mooring system. The tanker and the loading unit become one structure while loading or unloading. This results in less stringent dynamic positioning requirements for the oil tanker and greater operability and reliability of the system. The transportation and installation of this unit is similar to the CALM buoy, as claimed by the manufacturer.

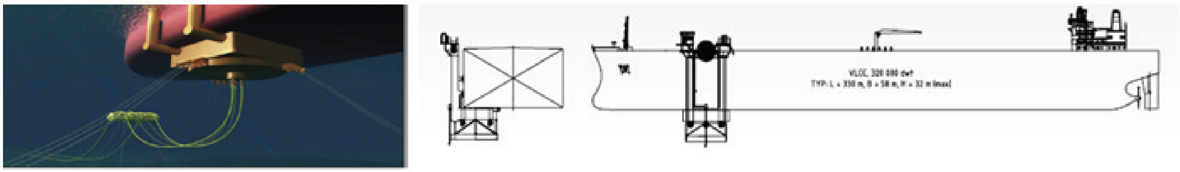


Figure 3-23: HiLoad loading/unloading system

3.4 TREATMENT OF IMPORTED WATER

3.4.1 *BACKGROUND*

Water treatment as we know it today has undergone many changes over the years since the first large scale water treatment for human supply began in the 17th century. Pre-treating water with alum and chlorination to kill bacteria and subsequent use of rapid sand filtration to remove suspended particles began for the first time in the late 19th century as a result of increase in population and rapid industrialization. Industrialization led to large scale waste discharges from industries ending up in the freshwater sources making them polluted and unfit for human consumption. This led to the creation of freshwater rules and regulations by national and international agencies like WHO (world health organization) setting drinking water quality standards. New technologies were created to cost-effectively remove specific pollutants from water and conform to the prevailing rules and regulations.

All surface water contains pathogens which have to be removed to be made fit for human consumption. The effectiveness of disinfecting water increases with the absence of turbidity or suspended solid particles. To remove the suspended particles a process of coagulation, flocculation, sedimentation, and filtration is used. Coagulants are chemicals which are added to water so as to eliminate the negative charge of the suspended particles which makes them repel each other. Aluminum or iron salts are usually used for this purpose. Some chemicals like activated carbon (to absorb taste and odor and absorb synthetic chemicals), chemical oxidizers (to oxidize organic and non-organic contaminants like iron, manganese and sulphide) and acid and bases to control pH of the water. Coagulated particles are aggregated into “flocs”, accomplished by gently stirring the water with water paddles or turbines. After flocculation the water is allowed to settle for few hours and then filtered, most commonly through 24-30 in (61-76 cm) of sand or anthracite having an effective diameter of about 0.02 in (0.5 mm)(69). Disinfection can now be carried out to remove harmful pathogens from water, done usually by adding chlorine to the water. All basic filtration and treatment plant around the world follow this methodology for treating water.

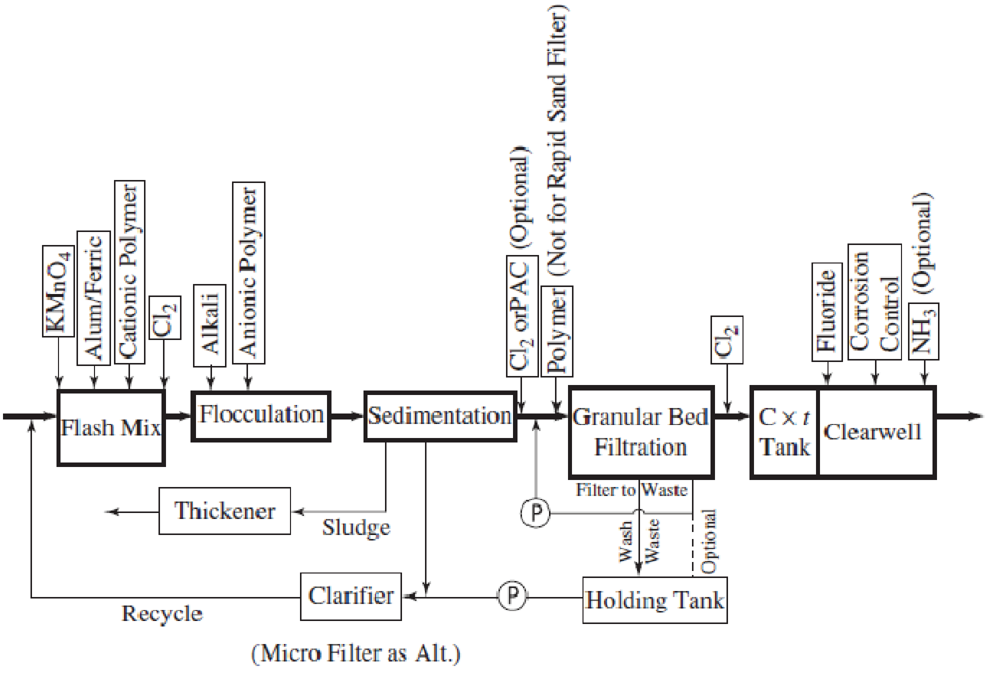


Figure 3-24: Basic water treatment plant **Source: (70 p. 11)**

3.4.2 *QUALITY, USE AND TREATMENT OF BACKHAUL WATER*

To utilize the freshwater imported from oil tanker ballast and cargo spaces effectively the following factors should be known :

1) Quantity of water imported
2) Quality of water from ballast and cargo spaces
3) Required quality of water for potable/agricultural and industrial usage

The quality of water imported depends primarily on the source of water and the extent of degradation of the water while being transported/transferred from the source to the point of unloading. Natural sources offer a wide variation of quality and constituents in the water in terms of dissolved organic and inorganic materials like animal, human and plant pathogens which are difficult to generalize. The water quality from the source should be continuosuly monitored while being used for FWBH trade, aimed at detecting harmful chemicals and toxins which might find their way to the water source due to human exploitation.

3.4.2.1 Quality of water when carried in SBT

The coating inside the SBT tanks is important to achieve minimal deterioration of the transported water and has a direct effect on the quality of the transported water in ballast spaces. A coating which can limit corrosion when carrying sea water ballast while not leaching any harmful chemicals in the freshwater should be sufficient to preserve/not cause further deterioration to the raw water/treated water when carried in ballast tanks. Some increase in the salinity of the freshwater is expected due to the remains of the seawater from previous sea water ballast carrying legs. This amount should be less than 0.1-0.2%[8] of the total ballast volume considering stripping and educting operations have been performed efficiently in the ballast tanks while de-ballasting. This would increase the sailinity of water by negligible amounts (10-15ppm, see Table 1.3 for comparison). Some biological deterioration can take place during the voyage due to the presence of micro-organisms and bacteria in the water. Using biocides in the SBT could stop this activity completely, but such results can only be predicted by a trial and use method. Good aeration should be maintained in any case inside the tanks. The water carried in SBT can be used as a source of potable water without any additional treatment requirements than those already being done at the point of comsumption (explained in chapter 3.4.1). In case of treated/high quality water being carried in SBT good quality painting scheme and de-ballasting arrangements like stripping and educting have to be employed to a higher degree so as to negate the effect of carrying sea-water ballast in the tanks on the FWBH leg.

3.4.2.2 Quality of water when carried in cargo tanks

The content of oil in the freshwater transported by use of cargo tanks varies for cargo tanks washed using COW before loading oil and direct loading of freshwater into cargo tanks after unloading crude oil. Cargo tanks have up to 0.5-0.7% oil remaning after unloading compared to 0.1-0.2% oil remaining in the tanks after they have been unloaded by simulataneous usage of COW (71). This results in a oil content of around 1-5 ppm after efficient COW has been performed. For freshwater in tanks not washed the oil content should be assumed to be more than 15 ppm. The composition and interaction of the oily residue with the water in the cargo tanks determines the final quality of water delivered.

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[8] Percentages assumed to be similar to the oil remaining in a cargo tank after COW

3.4.3 WATER QUALITY FOR AGRICULTURE

Water containing oil more than 15 ppm can be used to grow trees and shrubs or for watering amusement parks, golf courses etc (72). Various experiments have been done on varieties of seed types and environmental conditions to find the effect of use of oil contaminated water for agriculture purposes. A study by Tokyo University seems to prove that water with oil content of up to 50 ppm causes on problems in terms of absorption of hydrocarbons by plants (72). A study was also done at the Norwegian Oceanic Research Institute, Bergen for INTERTANKO to analyze the effect of light and heavy crude oil contaminated water on agriculture for human consumption. The results of the study were rather encouraging and showed little to no effect on the food products developed out of 2% oil in water by volume. Another experiment done by the National Academy of Scientific Research, Libya deduced the effects of oily water irrigation for up to 10% crude oil in water (72). The experiment also investigated the effect of oil contaminated freshwater (OCFW) which was defined as distilled water mixed with crude oil in the ratio 100:5 and mixed thoroughly. The mixture was then allowed to settle for 24 hours allowing some oil to rise to surface before removing the water to be used for irrigation. The results were measured on the basis of seedling growth length and percentage of germination of the crop. The results are listed in the following table:

Plant/Seed variety	Type of contamination	Effect on germination	Effect on seedling growth
Alfa alfa, corn, barley, wheat and peas	OCFW	NO EFFECT	Alfa alfa -reduced drastically
Cotton and Beans	OCFW	25% reduction	Very little effect
All	0.1 % crude	NO EFFECT	None to little effect
Corn	5% crude	NO EFFECT	Increased growth
Wheat	10% crude	NO EFFECT	Increased growth

Table 3.9: Effects of watering various crops with oily water **Source: (72)**

The encouraging factor here is the effect of OCFW was negligible on most of the plants except Alfa alfa. This indicates that using simple gravitational techniques and utilizing the decanted water for agriculture presents no harm to agriculture directly. The oily water can be used to irrigate crops not meant for consumption after determining the maximum contamination level. The indirect effect on soil and environment by using oil contaminated water for agriculture should be minimized by using different agricultural techniques (drip feeding/hydroponic techniques) and controlling the run-off of water to ensure no bio-accumulation of oil or other harmful products in the imported water take place. Further research and study have to done on such indirect effects of using oil contaminated water for agriculture.

3.4.4 WATER QUALITY FOR INDUSTRIAL USE

The use of water in industries is wide-ranging and process specific. It has been cited that oil content of 1ppm in water is acceptable for use (73).

3.4.5 Removal of Oil from Ballast Water

Oil and water can be separated by taking advantage of their difference in densities which acts the separating force when the emulsion is allowed to settle under the influence of gravity. This force is stronger between sea water and oil than freshwater and oil due to the higher density and electrical conductivity of seawater which facilitates the coalescing action of the small oil particles. Gravity can be used to bring the oil content in n water-oil emulsion to around 20mg/liters (20ppm). For further reduction in oil content the water gravity method has to be assisted with filtration and flocculation. Different treatments can be used for separating oil from oil in water emulsion at relatively cheap cost. Some of the treatment methods can be:

1) **Gravity separation and filtration using synthetic resins/ceramic blocks**: Synthetic resins which get wetted by oil and not by water is a principle which has been developed from the use of "Hay-box" during the early days of refining oil from water. This method provides good retaining capacity of the separated oil which can be utilized for further use. Using ceramic blocks coated with hydrophobic and oleophillic fluids generates an oil absorbing capacity of 3 times the weight of the ceramic block. The oil itself cannot be retained but its heating capacity can be by burning the ceramic for steam generation etc. These processes combined with a pre-gravity separation can reduce the oil content in the water to up to 5-10 ppm. The minimum waiting period required for greatest efficiency of gravity separation and filtration is important in view of the buffer/storage requirement in the system. A oil removal treatment plant which used a similar system as described above was installed at SUMED Sidi Kerir plant, Saudi Arabia for treating oily ballast from oil tankers during the 1980s had a throughput of 150,000 m^3/day. The system was used for refining oil from 2000-3000 ppm in the ballast to under 6 ppm for safe disposal of ballast in the ocean.

2) **Air floatation, flocculation and filtration**: Flocculation is an effective method to remove oil residuals from water by adjusting the pH of water to facilitate formation of flocs or small masses of fine particles. This process can be followed by air floatation, which is high pressure air is dissolved in water and subsequent release of pressure forming small bubbles of air in the water. These bubbles attach themselves with the suspended particles in the water, which is pre-dominantly oil in this case, causing the particles to rise to the surface forming froth. The floating froth can be skimmed from the surface manually or by mechanical means. Using a membrane with very small pores(<0.005 microns) in this process can further help to remove oil particles which are too big to pass through the membrane, leaving behind a concentrate of emulsified oil droplets and suspended particles.

3) **Activated carbon**: for additional removal of organic constituents from water powdered material of activated carbon can be well mixed in water to be removed by filtration. This process would yield water with less than 1ppm oil.

Water Use	Treatment process
Agriculture	1)
Industry	1) + 2)
Potable	1) + 2) + 3)

Table 3.10: Treatment options to employ, depending on water area of use

3.4.6 INTEGRATION WITH EXISTING SUPPLY/TREATMENT SYSTEM

Due to the nature of treatment (depending on water transported in SBT or cargo tanks) and usage (agricultural, industrial or potable use) of the imported water the integration of the imported freshwater to the point of consumption can be done in several ways.

- For agricultural use the water can be pumped directly to a reservoir by using canals or conduits, utilized after allowing a settling time of at least 24 hours to facilitate gravity separation in case of water carried in cargo tanks. Frequent monitoring and testing of water is required to ensure no harmful imported pathogens are present in the water.
- A new "industrial" agricultural area can be envisaged which is catered by the FWBH water allowing direct unloading to the agricultural fields.
- For regions which have a separate water supply system for direct human consumption like cooking, bathing etc and indirect human use like gardening, sewage (blackwater) relatively simpler treatment process can be introduced in the existing system with greater ease to incorporate the use of imported water.
- Where the quality of raw water is relatively high and transported using SBT the water can be directly pumped in to the existing reservoirs of water consumption. Frequent monitoring and testing of imported water is required in this case.
- For specific industrial processes where lower quality water can be used relatively cheap treatment methods or no treatment in case of good quality freshwater transported in SBT is required. In this case direct unloading of water to the point of consumption/ storage is possible. This is only true if the water supply for industries is separated from the city water supply, which is rarely true but can be possible for certain water deficient regions, such as the city of Jubail, Saudi Arabia(73).
- In all other cases a separate dedicated treatment facility should be provided for water carried in SBT and cargo tanks. The level of treatment can be reduced by connecting the treatment plant to the already existing main treatment facility. Minimum quality equivalent to the locally available raw water is to be maintained.

4 ECONOMICAL ANALYSIS

If any practical, contractual and legal issues can be dealt with, the feasibility of freshwater backhauling in ballast or cargo tanks primarily depends on the costs. If such a scheme can be proven to be cost-efficient and even profitable for all parties involved, a certain driving force is created.

As outlined in chapter 1.3.2.4 , some studies was carried out in the 1970s and 80s, examining freshwater backhauling in detail. It is clear, however, that much has changed since the last reports were published, and there is need for updates cost estimates, taking into account not only current tanker market conditions and water supply & demand, but also the vast developments in tanker design, water handling equipment and infrastructure and new water supply augmenting technologies.

4.1 METHODOLOGY

Since the cost of a FWBH operation is highly dependent on an enormous array of parameters, we conclude that the most appropriate manner in which to assess the concept both on a general and scenario-specific level is to create a general, mathematical economical model. This allows us not only to conclude whether or not FWBH will be economically viable for different scenarios, but also to analyze what are the most important external parameters in determining this viability.

As chapter 3 details, the amount of technical adaptation and new equipment required for FWBH depends on the project conditions, and ranges from a few extra pumps and a purification system at the fresh water unloading terminal to ship modifications and completely new piping, reservoirs and terminals at all ports involved. The total cost per ton of water supplied in this way thus depends on investments needed to facilitate such a trade as well as the costs arising from operation. Figure 4-1 illustrates one way of grouping the costs.

When calculating the direct cost from transporting the water we define this as the “additional” cost arising from the fresh water operation. The purpose of the model as a whole is to calculate the break-even cost, i.e. the lowest possible total price the water importer would have to pay for the water.

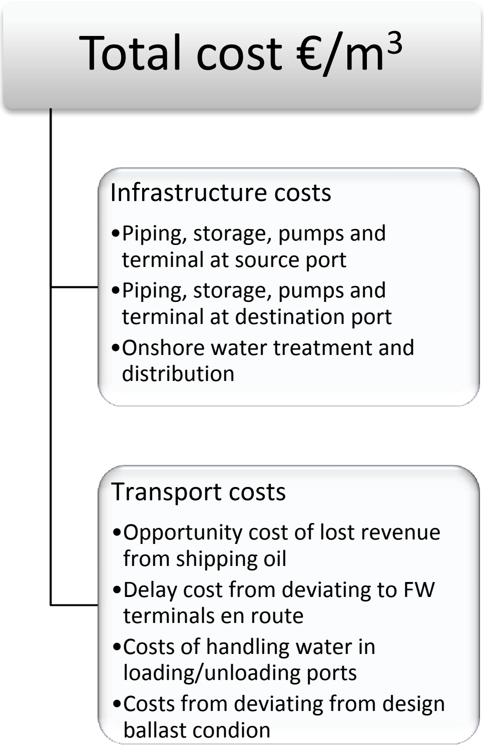

Figure 4-1: Cost partitioning of FWBH scheme

4.2 ECONOMIC MODEL

The transport cost of fresh water backhauling with oil tankers is a mentioned above made up of any increase in operational costs and opportunity costs. How to calculate this depends on the type of contract the ship is sailing on. If, for instance, the vessel is owned by an oil company using it only for transporting oil on a long term basis and the only goal is to minimize costs, the ship is sailing in what is called industrial shipping. One can envision that in this case the shipowner will not be able to secure more profit by taking on more shipments of oil, and as such only the increased operational expenses will constitute the transport cost of FWBH. If the vessel is trading on the spot market, on the other hand, any time lost is also profit lost.

The transport costs are modeled in the following way:

$$C_T = DEV_T + LD_T + DBC_T$$

$$DEV_T = C_{DEV} \cdot (t_{DEV,loading} + t_{DEV,unloading})$$

$$LD_T = C_{LD} \cdot (t_{FWloading} + t_{FWunloading})$$

$$DBC_T = C_{DBC} \cdot t_{DBC}$$

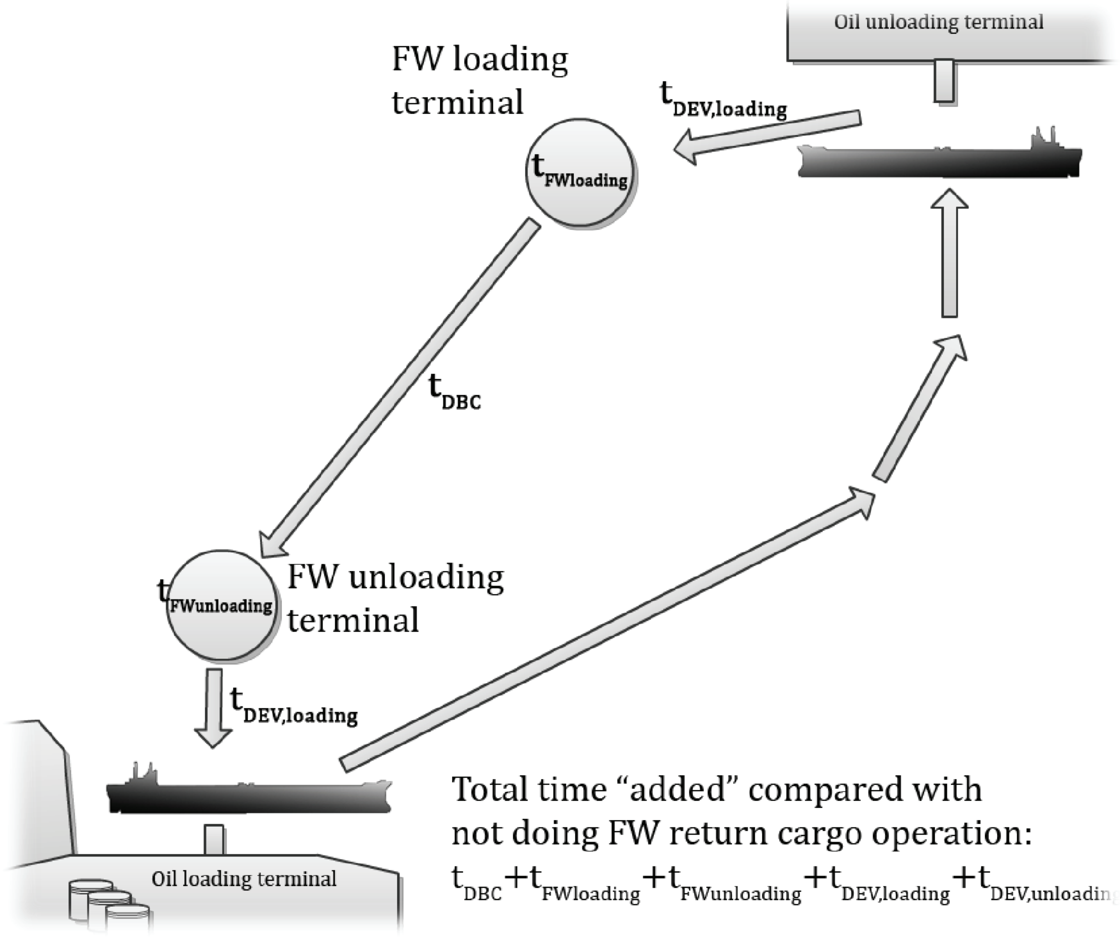

Figure 4-2: Graphical illustration of some variables in the FWBH scheme

DEV_T accounts for the costs associated with deviating to fresh water loading/unloading terminals, if these are not situated together with the oil terminals. Time lost to deviating is a function of distance to the water terminal and sailing speed.

LD_T includes costs from spending time in port loading/unloading fresh water, and is a function of pump capacity and amount of water carried. If water handling in port can be performed simultaneously with handling of oil the time lost, and consequently the cost, is zero. Here it is also possible to include port charges, if applicable.

DBC_T depends on the extra time spent on the ballast leg if more than the standard (minimum) amount of ballast water is loaded onboard. This is approached in a simple way in this model[9]: Based on the input of sailing speeds in fully loaded and (normal) ballast condition, the difference in time spent on one leg between the two ports is calculated. If the standard ballast load is 30% DWT then any increase in ballast will linearly increase the time taken on the ballast leg, up to 100% DWT ballast which gives the two legs equal duration.

For instance, if design and ballast speeds are set at 16 and 17 knots, respectively, distance between ports is 4000 nm and 70% DWT of fresh water is carried, the calculation becomes as follows:

$$t_{DBC} = \left(1 - \frac{100\% - 30\%}{100\% - 70\%}\right) \cdot (250 - 235) = 6.3 \text{ [hr]}$$

The values of C_{DEV}, C_{LD} and C_{DBC} vary with applicable freight rate and/or operational costs. When considering opportunity costs (or *freight rate costing*) costs depend only on the combined time lost, so $C_{DEV}=C_{LD}=C_{DBC}=$ [Freight rate]. When calculating minimum operational expenses excluding any additional port fees we get the following,:

$$C_{DBC} = C_{DEV} = OPEX + F_{cons} \cdot F_{price}$$

$$C_{LD} = OPEX$$

Where F_{cons} and F_{price} is fuel consumption and cost, respectively, per unit of time; OPEX accounts for all other operational expenses, again per unit of time. All three can either be known, based on an existing vessel or fleet, but are also easy to estimate using reference databases.

In order to get the most realistic and complete cost estimate, the infrastructure costs should cover capital and operational expenses across the whole logistic chain from water source to consumer. This does, of course, depend on how the scenario is defined, and if comparing costs with – say – desalination one must take care to include the whole chain relevant there as well. As for transport costs, the only real expenses from FWBH are the ones you would have to **add** to the normal expenses from standard operation. The implementation of infrastructure costs in the model is limited, as it does not calculate them based on other input variables, but requires the user to know what infrastructure is required and what it costs. To estimate total port side expenses mathematically one would still have to have extensive knowledge of what facilities are required, as well as statistical data on a wide range of facilities and equipment, and such an exhaustive approach is deemed beyond the scope of this report. Infrastructure cost is divided

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[9] This linear relationship assumes that one would/could not minimize or perhaps eliminate the delay by increasing engine output.

into capital costs and operational costs, and to estimate total expenses one must know what equipment, facilities and modifications to procure and the cost of these. The next chapter provides one example of complete infrastructure evaluation.

In addition to the aforementioned expenses would be the price of water at source. This would depend on market conditions, but also who is to carry the cost of infrastructure at the source port. In the model as applied in this chapter no price of water has been included, and it is assumed that the water importing party bears all costs.

4.3 ANALYSIS

In order to apply the model on a realistic scenario and produce accurate cost information for FWBH within the scope of this report, we have decided to focus our efforts. One Middle-East oil exporting port is selected and costs for shipping fresh water to this port through FWBH from a selected port will be calculated. Costs will be calculated for a range of project parameters.

The holistic approach adopted in this chapter presents us with some challenges, and foremost amongst these is the issue of acquiring information on ports and accurate cost figures for equipment needed. As a certain level of uncertainty, at any rate, inevitably will be present in an analysis like this, educated assumptions are in effect as important as hard data. Still, a great deal of effort has gone into fact finding, and no figure in the following is without empirical backing.

4.3.1 SCENARIO

When selecting the route or ports to analyze in a scenario such as this it is important to do it in such a way that any conclusions yielded by the analysis can be made applicable to a wide range of different scenarios. In other words, care must be taken to make sure the results are as useful as possible. It is with this in mind we opt to investigate the costs of a FWBH scheme for the crude shipping trade between the ports of Ras Tanura, Saudi Arabia and Chiba, Japan.

Saudi Arabia ranks in the top, globally, in terms of dependency on desalination and accordingly has the potential to become a major fresh water importer. The port of Ras Tanura, situated in the Arabian Gulf, is the world's largest oil loading terminal (74). The region around the port include several huge desalination plants, in total accounting for almost 50 % of Saudi Arabia's total desalination capacity in the Arabian Gulf (see Figure 1-8, page 13). This gives that an extensive water distribution and treatment network already exists in the proximity of the port, and combined with the large quantity of tankers visiting every week it becomes clear that Ras Tanura has potential for handling and distributing large amounts of fresh water imported by way of returning crude oil tankers.

Japan, being the second largest importer of oil in the world, gets most of its oil from the Middle East. The island of Yakushima, sited right on the trade route between the Arabian Gulf and the Japanese archipelago (see Figure 2-3 or Appendix B), it considered one of the best fresh water sources in terms of yield, environmental impact and location. If developed, it has the potential to supply huge amounts of fresh water as return cargo to tankers passing on the way to the Middle East. The choice of which oil handling port in Japan to consider becomes of less importance once Yakushima has been chosen as the fresh water source, as almost all tankers trading with Japan sail close to Yakushima regardless of the main (oil) port of call. A port must nevertheless be selected to provide a quantitative basis for analysis; here we opt for the port of Chiba. Situated just outside of Tokyo, it is the second largest in Japan in terms of cargo handled per year. More importantly it is the primary port for serving the very densely populated Tokyo hinterland with oil products and so it receives several VLCCs each week (75).

The scenario to be analyzed is consequently as follows: Find the cost per ton of fresh water when it is carried either as fresh water ballast or backhaul cargo in the main tanks to the port of Ras Tanura, Saudi Arabia, from the port of Chiba, Japan when the water is taken from Yakushima Island. The water is to be used primarily for agriculture. When it is carried as fresh water ballast it is carried in the vessel's segregated ballast tanks, and when it is carried in the main cargo tanks the ballast tanks are not in use.

For purpose of simplicity the ship type used will not be varied, but set at a modern 300.000 DWT VLCC. Lifetime of the project is to be set at 15 years, with a 5 % average interest rate (real). To the highest degree possible, the quantitative analysis should include the whole logistical chain to provide the most realistic total cost.

4.3.2 OIL DISCHARGE/WATER LOADING

The distance between the oil unloading terminal at Chiba and the fresh water source at Yakushima Island is approximately 600 nautical miles. When sailing from Chiba to Yakushima the vessel must carry seawater ballast. Another issue with this concept is that the island itself does not have any infrastructure in place to serve large amounts of fresh water. The advantages are that the island has a very high supply of fresh water, which is not used for any other purpose, and it sits in the middle of one of the busiest shipping lanes in the world – meaning that it would not be a large detour to deviate there to load water.

Yakushima port cannot accommodate very large tankers, so the only option in terms of berthing system is a buoy mooring system. Other elements of infrastructure needed include a reservoir, pipes and pumps. See chapter 3 for a more detailed technical description of these systems. A graphical illustration of the complete system proposed is shown in Figure 4-3. The figure also includes a small hydroelectric plant; though not required, it could be fitted to provide electricity for the powerful loading pumps and other consumers. The supply infrastructure could also be located near to one of the existing hydroelectric plants on the island.

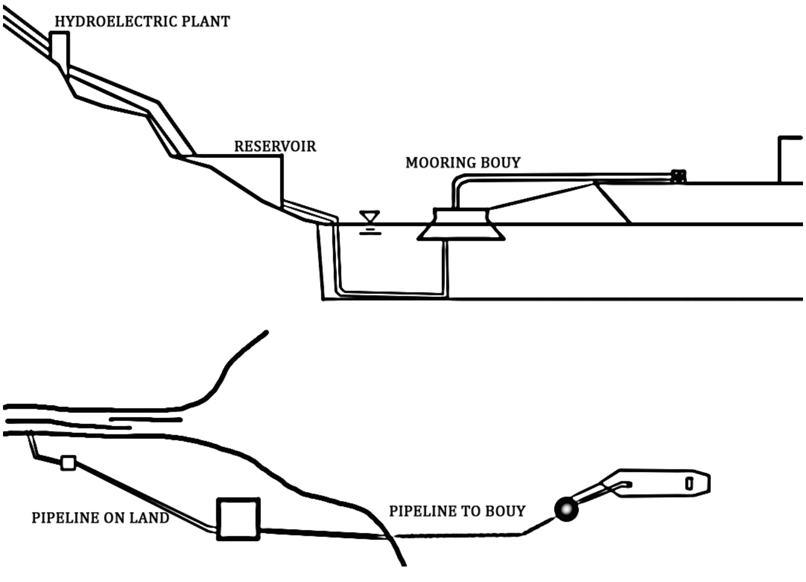

Figure 4-3: Illustration of proposed infrastructure on Yakushima Island

To make sure we find the minimum cost we must maximize the amount of water transported with the selected assets. This is also to make sure that the capital cost of the infrastructure does not make up an unrealistically large portion of the total costs. We assume that the buoy will be occupied 20 % of the time, and set the pump capacity at 20,000 m^3/hr. Fixing the yearly throughput in this way allows scaling of the complete system, and should keep the fraction of infrastructure to total costs relatively fixed. To minimize any waiting time if two vessels arrive at the same time two or more buoys could be constructed. For the purpose of this analysis one buoy is deemed sufficient, but in any real-life FWBH proposal a more detailed analysis of port-side infrastructure would of course be required. This would be especially important when considering the ballast case, in which more ships would be employed in the fleet and the probability of two ships being in the same area at the same time is higher.

This leads to a yearly throughput of fresh water of 35 million tons, which is near the upper region in terms of what Yakushima Island potentially can supply. By fixing the amount of water to be carried per ship at 100% DWT and 30% DWT for the cases using cargo tanks and ballast tanks, respectively, we see that we need approximately 13 versus 43 ships to carry the specified amount each year. For determining required reservoir size we follow the calculations in chapter 3.3.3.4, page 41. If 50 million tons per annum is the potential output, the reservoir would be replenished at a rate of 5700 tons per hour[10], so it would take 52 hours to refill 300,000 tons of water is a VLCC's cargo tanks have just been filled. With just 13 ships in the scenario where cargo tanks are employed the chance that two or even three ships will arrive right on top of each other is very low, so a reservoir size of 600,000 m^3 is deemed sufficient to allow for irregular arrivals.

Table 4.1 summarizes the infrastructure required and the associated costs. The costs themselves have been based on a variety of sources, notably PEIDA (1980)(73), Intertanko (1983) (76) and Kimberley Water Supply Panel (2006)(31), and although actual costs of a real project likely would differ from the figures used here we believe they are realistic enough for the purpose of this feasibility study. Operating and maintenance costs are estimated at 10 % of initial investment cost yearly.

Element		Unit cost US$	Total cost US$
SPM system	1	40,000,000	40,000,000
Booster pump stations	1	20,000,000	20,000,000
Pipeline, land	1000m	5,000	5,000,000
Pipeline offshore	3000m	5,000	15,000,000
600,000 m^3 reservoir	1	6,000,000	6,000,000
Total capital costs			86,000,000
Infrastructure operation and maintenance, yearly			8,600,000
Cost, US $/m^3 water			0,30

Table 4.1: Costs of infrastructure required on Yakushima Island for the purpose of fresh water loading of VLCCs

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[10] Yakushima Island is the wettest place in all of Japan, and although more rain falls in the spring months the precipitation levels are stable the year around.

4.3.3 OIL LOADING/WATER DISCHARGE, TREATMENT AND STORAGE

The port facilities at Ras Tanura (see Appendix A) were created chiefly to cater for oil and product tankers, and in terms of other facilities it is fairly limited. This means that any infrastructure associated with water reception must be built from scratch. Of all the terminals only the Sea Island is capable of handling VLCCs. Only 4 out of 8 berths can accommodate ships above 300,000 tons DWT. Crude oil loading facilities have capacities ranging from 4000 m^3/hr to 22000 m^3/hr, with the average VLCC visiting for about 24 hours, including time spent bunkering(77).

There are essentially two options with regards to how to construct the reception facilities at Ras Tanura: One could either build one or more buoy mooring systems with corresponding pipes carrying the water to shore, or facilities could be built on the Sea Island itself. The latter option certainly seems more attractive at first glance, in theory allowing simultaneous unloading of water and loading of crude oil and thereby reducing time in port. This is especially true if the water is carried only in ballast tanks. If cargo tanks are used instead, a delay would occur while the tanks are partially unloaded, before loading of oil could begin. Although time spent in port still will be lower, in this case, with collocated facilities, the vessel could take up valuable berth time meaning that other tankers not involved in the FWBH scheme also might have to wait.

If water is carried in cargo tanks only, the ship's powerful cargo pumps would handle the offloading of water. If ballast tanks are used, on the other hand, additional pumping equipment would be required, as outlined in chapter 3.2.

Element		Unit cost US$	Total cost US$
Water treatment investment	1	20,000,000	20,000,000
Modifications to Sea Island	1	40,000,000	40,000,000
Pipeline to shore	8000m	5,000	40,000,000
Pipeline to storage/ treatment/ distribution	1000m	5,000	5,000,000
Pumping station	1	10,000,000	10,000,000
Total capital costs			115,000,000
Infrastructure operation and maintenance, yearly			9,500,000
Water treatment costs			2,000,000
Cost, US $/$m^3$ water			0,40

Table 4.2: Costs of infrastructure at Ras Tanura, with Sea Isl. modified to receive fresh water

Element		Unit cost US$	Total cost US$
Water treatment investment	1	20,000,000	20,000,000
Mooring buoy	1	40,000,000	40,000,000
Pipeline to shore	5000m	5,000	25,000,000
Pipeline to storage/ treatment/ distribution	1000m	5,000	5,000,000
Pumping station	1	10,000,000	10,000,000
Total capital costs			100,000,000
Infrastructure operation and maintenance, yearly			8,000,000
Water treatment costs			2,000,000
Cost, US $/m^3 water			0,35

Table 4.3: Costs of infrastructure at Ras Tanura, with water unloading at buoy

The various unit costs have been determined in the same way as in chapter 4.3.2.

This chapter will not go into detail on the type of water treatment equipment used, but it is assumed that some level of oil removal is required along with removal of other impurities. To establish an estimate of the total treatment costs at Ras Tanura papers previously published on the subject, by Gordon (1983) (71) and Marson (1983)(78), serves as the baseline. This is then modified and updated to serve the purpose of the current scenario by the use of modern water treatment cost estimation literature, notably Kawamura's *Integrated design and operation of water treatment facilities*(2000) (79) and Kawamura and McGivney, *Cost estimating manual for water treatment facilities*(2008) (70). An investment price of 20 MUSD is close to what reference literature estimate a plant of this size would cost. Yearly operational and maintenance costs for this facility, at 2 MUSD, is actually quite a lot more than assumed elsewhere; the upper estimate is used here to reduce the possibility of underestimating the costs.

The cost of treatment will of course vary with the initial quality of the water and its oil content, if any, and with the intended use for the water. Other reports point to percentage-wise differences as shown in Table 4.4. This is a topic deserving of its own research paper, though, so when calculating total costs we, for purpose of simplicity, assume a oil content of below 15 ppm, and agriculture as the primary destination for the water. As treatment is handled in a very general and simple way in this chapter, we refer to chapter 3.4 for in-depth description of water treatment systems.

Water quality	Intended area of use	Cost
Non-oil contaminated water	Agricultural	100 % (baseline)
	Industrial	100 %
	Drinking	100 %
Oil contaminated water	Agricultural	200 %
	Industrial	250 %
	Drinking	300 %

Table 4.4: Relative difference in treatment costs per m^3 of water transported by tanker **Source:** (73),(78)

4.3.4 TRANSPORT COSTS

The transport costs of this project can, be calculated using operational expenses or freight rates. In Table 4.5 is summarized the transport costs for shipping 35 million tones of fresh water to Ras Tanura from Japan each year using a tanker backhauling scheme. It is assumed that loading of oil and unloading of water is possible only when water is carried in ballast tanks and water reception facilities are located at Sea Island. In all cases the water loading and unloading rate is set at 20,000 m^3/hr. See the appendix for an overview of spreadsheet calculations.

Offloading water at buoy	Water is carried in ballast tanks (30% DWT)		Water is carried in cargo tanks (100% DWT)	
	OPEX[11]	Freight rate[12]	OPEX	Freight rate
DEV$_T$	0.18	0.23	0.05	0.07
LD$_T$	0.05	0.23	0.05	0.23
DBC$_T$	0.00	0.00	0.05	0.19
Total, US$ per m^3	0.23	0.46	0.15	0.50

Offloading water at Sea Island	Water is carried in ballast tanks (30% DWT)		Water is carried in cargo tanks (100% DWT)	
	OPEX	Freight rate	OPEX	Freight rate
DEV$_T$	0.10	0.12	0.03	0.04
LD$_T$	0.03	0.12	0.05	0.23
DBC$_T$	0.00	0.00	0.05	0.19
Total, US$ per m^3	0.13	0.24	0.13	0.46

Table 4.5: Transport costs for FWBH from Chiba to Ras Tanura

It is clear from this table that only when water can be unloaded at the same time as oil is loaded is it much cheaper to use only ballast tanks compared to full cargo tanks. The savings from unloading water at the same terminal where oil is loaded are substantial when ballast tanks are used, but insignificant when cargo tanks are used. This is because of the huge amount of water that needs to be pumped out before loading of oil can begin, whereas when only ballast tanks are used loading of oil can, theoretically, begin simultaneously with water unloading.

When the vessel is loaded with 100% fresh water it is able to capitalize on some economy of scale benefits, driving the cost of deviating to pick up or discharge water down, but it suffers from reduced speed on the return leg.

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[11] Operational expenses for a VLCC based on Drewry's *Ship Operating Costs* (98). Fuel price assumed at 450 US$/ton.

[12] The freight rate used is the average rate at the time of writing, of approximately 50,000 US$/day, which incidentally is very close to the average rate over the last ten years (77).

4.4 SENSITIVITY

The model as presented and its application on a set scenario allow us to make some useful observations as to what decides whether or not FWBH can be economically feasible. Only transport costs can be quantitatively evaluated in terms of sensitivity, as a modeling of variation in infrastructure costs proves too complex for the purpose of this report. This does not mean, however, that infrastructure costs cannot be discussed and evaluated. Interesting topics in evaluating the economics of FWBH is not only how changes in project parameters affect cost but also the impact of external factors; both will be discussed in this chapter. It should be mentioned that this chapter does not aim to address contractual issues with FWBH – this is done in chapter 5 – but the economics of this concept are closely related with the agreements that would facilitate it, and so both matters should be viewed in combination.

PORT INFRASTRUCTURE AND LOCATION

It follows from the model used that if fresh water and oil reception and loading facilities are collocated, and it is possible to load/discharge water whilst loading or discharging oil, transportation costs when only using segregated ballast tanks are zero. The facilities and equipment present at the terminal, together with port authority regulations, will determine if this is possible or not. If the ship is fully loaded with fresh water in its cargo tanks, however, is will not at any rate be possible to begin loading oil before most or all of the water has been discharged. Another important infrastructure element in this regard is the capacity of the water reception terminal. If the water cannot be transported away from the vessel at the same speed as the highest potential pumping capacity, a bottleneck is created and more time must be spent in port. It is reasonable to assume that it would be economic to maximize throughput at the reception terminal, at least if a significant amount of water is sought to be handled and especially if simultaneous oil and water handling is not possible. In accordance with Table 4.5 port throughput is more important when costing by opportunity costs than pure operational expenses, as port-side costs (LD_T) then make up about 50% of the combined transport costs.

When it comes to port location there are two elements to factor in. One is the distance between the oil loading and oil unloading port themselves; the other is any distance the ship has to deviate to reach either the water loading terminal or water unloading terminal or both.

In Figure 4-4 transport costs between a large range of ports has been computed, for different levels of fresh water loading, and shown graphically. The figure assumes that in the 30% DWT case only ballast tanks are employed, but for any higher percentage only cargo tanks are used. No simultaneous handling of cargo was allowed in the underlying calculations. It is assumed that water loading and unloading terminals are in close proximity to the oil handling terminals, but a 2 hour delay has been added in each port to account for time spent handling water reception equipment or moving the vessel from one terminal to the other. The figure shows that there is a “tipping point” distance, below which the use of cargo tanks instead of ballast tanks is more economical. In this case, with the aforementioned boundary conditions, that distance is approximately 3500 nm. The reason for this “behavior” is that once the tipping point distance has been reached the speed reduction due to deviation from standard ballast condition, DBC_T, takes over as the primary cost. At shorter distances port expenses dominate.

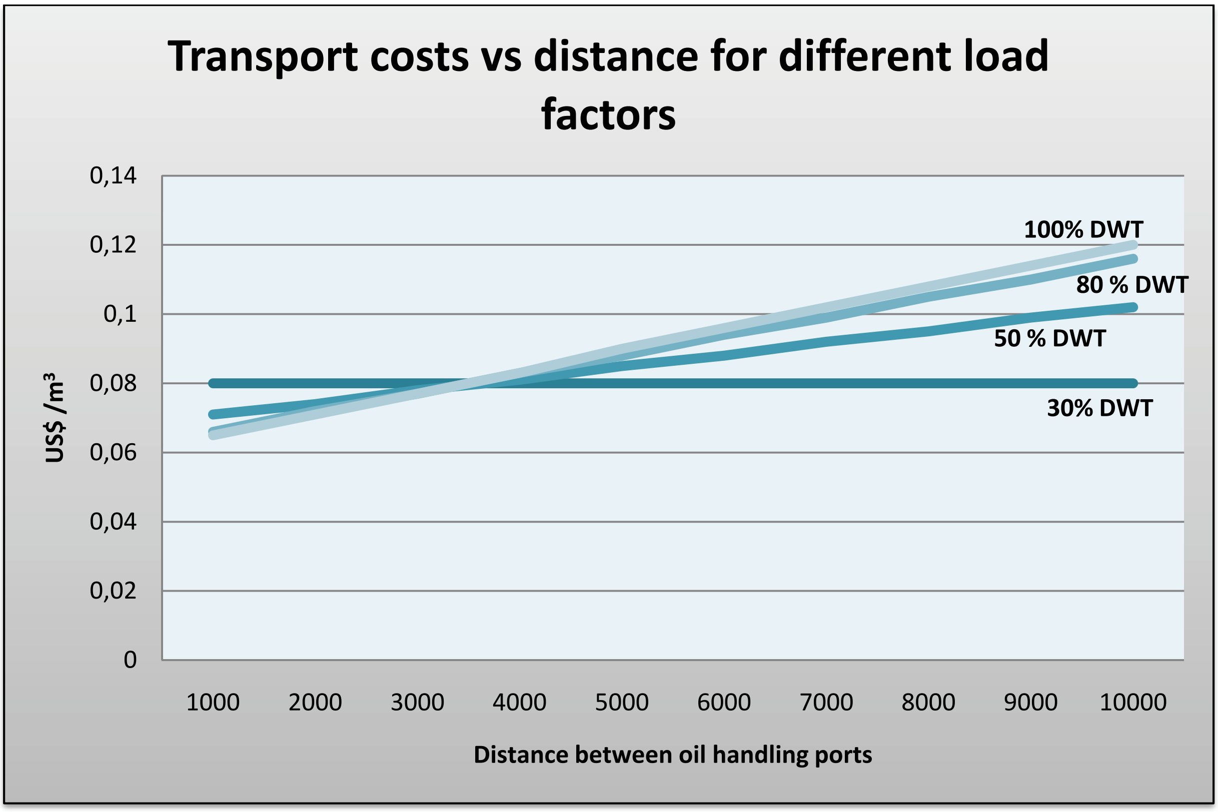

Figure 4-4: Effect of distance between ports on transport costs for different grades of loading

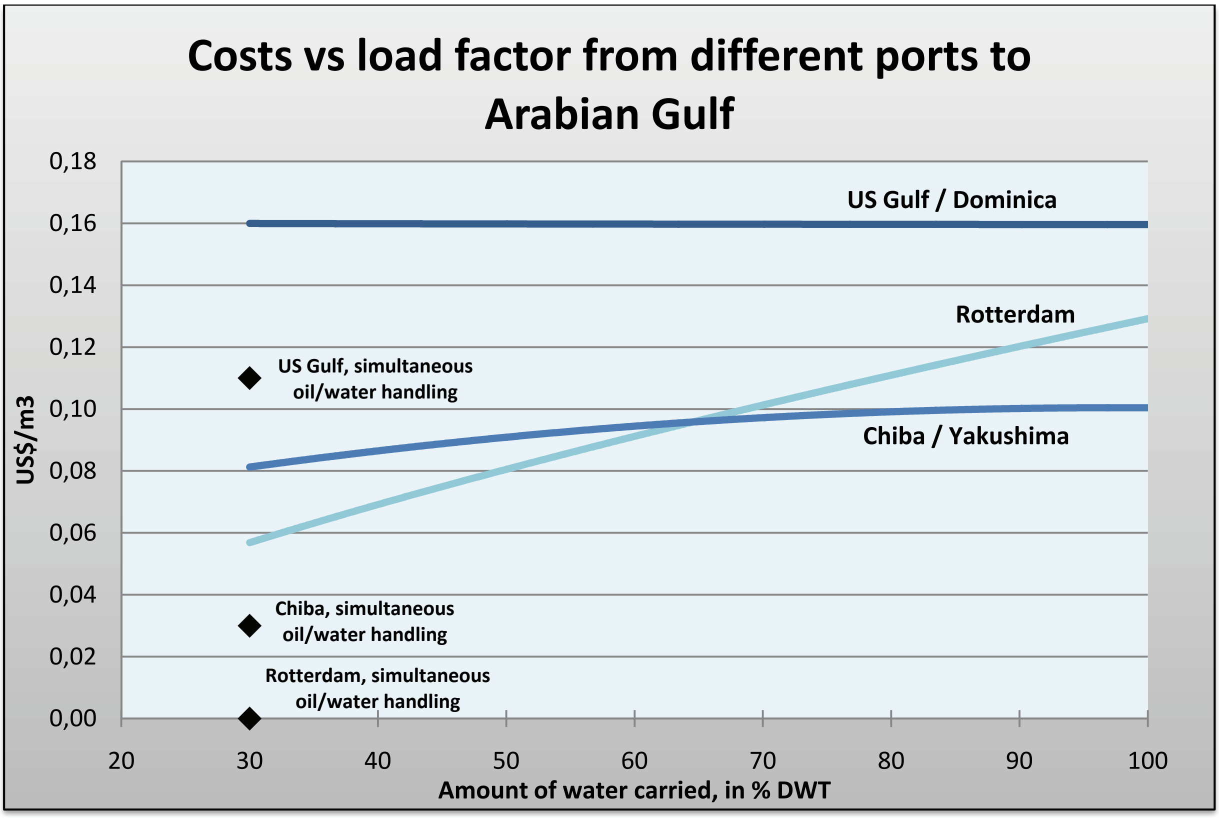

Figure 4-5: Transport costs versus level of loading from different ports to the Arabian Gulf

DISTANCE TO DEVIATE

This should again indicate that the shorter the distance, the more important the distance to deviate or time lost in port. The next graph actually indirectly illustrates one aspect of the importance of distance to deviate, or DEV_T. An important attribute of this parameter is that it shifts the tipping point exhibited in Figure 4-4. This is visible in Figure 4-5; take for instance the case of backhauling water from US Gulf / Dominica to the Arabian Gulf. Here we are clearly situated right on top of a tipping point, with costs unchanged despite any change in load factor – even though the distance between oil handling ports is more than 12000 nm. Compared with Figure 4-4 the tipping point has been shifted from 3500 nm (with no distance to deviate) to 12000 nm, due to the 400 nm a vessel would have to deviate to load water from the island of Dominica on the return leg.

MARKET CONDITIONS

Changes in both the oil market and tanker market will both affect FWBH, both in terms of general feasibility but also the way in which it would be most economical to achieve it.

Higher oil prices would most likely mean higher freight rates, and would have a significant impact on transportation costs if these are determined by freight rates. Higher oil prices would also mean higher fuel prices, increasing transportation costs whichever way it is calculated. As higher freight rates increase transport costs evenly across all elements in the equation on page 53, higher fuel prices would only increase voyage costs, increasing the importance of time lost at sea vis-à-vis costs in port. In both cases the costs of FWBH is very sensitive to variation in fuel price. At very high oil prices it would be unfeasible to use cargo tanks to transport water, as it takes too much time. If high enough, only one alternative could remain feasible, namely using ballast tanks only and unloading/loading water simultaneously with loading/unloading oil.

Figure 4-6 and Figure 4-7 exhibit isocost curves illustrating how the feasible region in terms of distance to deviate and load factor vary with changes in freight rate, based on a “ceiling” on transport costs set at 0.60 US$/m^3. With this specific upper limit we see that with a freight rate of 30,000 US$/day it would be possible to deviate up to 1000 nm in total to visit a fresh water supplying port. When the rate is doubled very little deviation is possible, and it would not be economical to load more than 50% of the vessels deadweight with water on the return leg.

Practical usage of figures such as these requires establishing the maximum cost one would be willing to carry for transporting the water, as well as historical knowledge about freight rates on the desired route. For instance, over the past ten years rates for a VLCC between Japan and the Arabian Gulf have varied between 20,000 and 90,000 US$/day(80). If the transport cost ceiling remains at 0.60 US$/m^3 it is obvious that what load factor and deviation distance is feasible is strongly dependent on market conditions, and will fluctuate strongly in the long term.

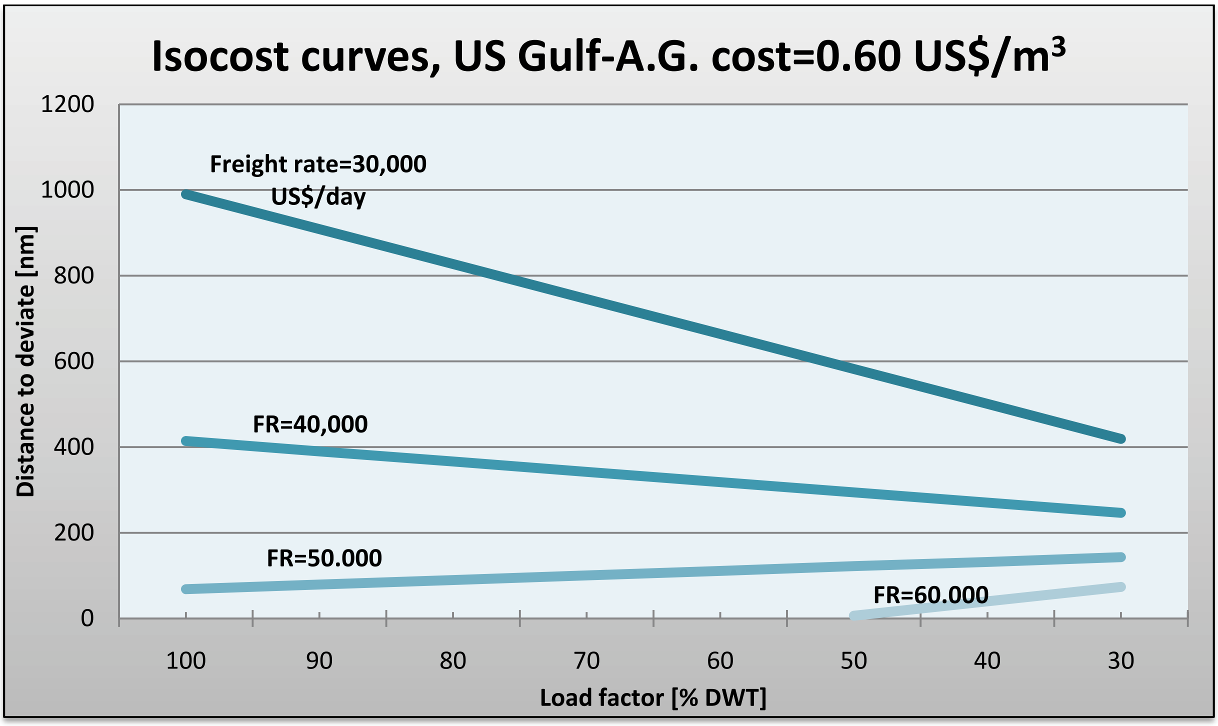

Figure 4-6: Isocost curves for different freight rates, between US Gulf and Arabian Gulf

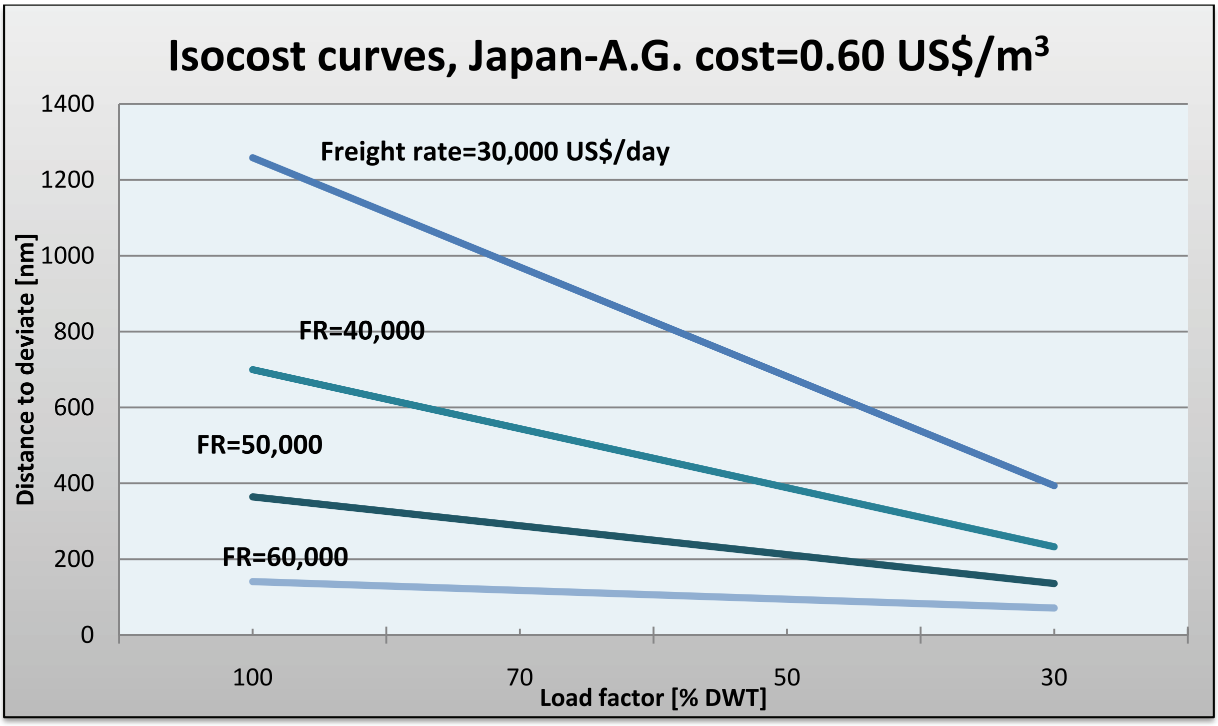

Figure 4-7: Isocost curves for different freight rates, between Japan and Arabian Gulf

SHIP SIZE

Ship size does have an impact on the cost-effectiveness of FWBH, as the principle of economy of scale applies also here. Generally this means that the larger the ship the lower the cost per ton, and when mathematically evaluating transport costs alone it is without a doubt true. In fact, a Aframax at 100,000 dwt performing the same service as the VLCC(s) in chapter 4.3 will, as estimated in the model, incur a 50 % higher cost. That even assumes that loading and unloading rates remain unchanged, which the most likely would not. But there are other elements to consider, foremost amongst these is draft limitations. In virtually any scenario there will be a upper limit to how large ships that can be accommodated; of all twenty berths at Ras Tanura, for instance, only four are available for VLCCs. Also, in a scenario like the one analyzed here, the fleet used in the water backhaul trade would often be heterogeneous, with ships of a wide range of sizes participating in the undertaking. This would have to be taken into account when designing port infrastructure, to have terminals capable of serving different ship sizes and types in both the water loading and water unloading port. Compared with the capital costs estimated for the scenario in the previous chapters, though, additional expenses would not necessarily be of a significant magnitude.

4.5 CONCLUSION

In this chapter we have concluded that shipping 35 million tons of fresh water from Japan to Saudi Arabia as backhaul cargo will have a approximate total cost of between 0.83 and 1.16 USD/ton. Combining the figures determined in the previous chapters results in the total cost estimates, shown in Table 4.6.

	Transport costs OPEX/Freight rate	Infrastructure Ras Tanura	Infrastructure Yakushima Isl.	Total
30% DWT, unloading at Sea Isl.	0.13 / 0.24	0.40	0.30	0.83-0.94
30% DWT, unloading at bouy	0.23 / 0.46	0.35	0.30	0.88-1.11
100 % DWT, unloading at Sea Isl.	0.13 / 0.46	0.40	0.30	0.83-1.16
100 % DWT, unloading at buoy	0.15 / 0.50	0.35	0.30	0.80-1.15

Table 4.6: Total cost estimates for FWBH scheme carrying ~35 million tons fresh water between Japan and Saudi Arabia, USD/m^3

These figures include almost all anticipated infrastructure required, and is calculated for the operational expenses and freight rates at the time of writing. What is not included is storage and distribution in receiving port, and modifications to the ships themselves, if required.

Transport costs is possible to estimate with mathematical modeling, whereas infrastructure and operation costs is virtually impossible to model as they are completely dependent on the existing facilities and conditions. A more general overview of the transport costs of FWBH is presented in the below table. A more case-by-case specific approach is required to calculate the total costs, but Table 4.7 at the very least provides a good starting point; in fact, if port-side infrastructure is already present or costs associated with this negligible the only cost is the transport cost.

Distance between oil ports	Transport mode	Total distance to deviate to load/unload water	OPEX costing	Freight rate costing
Low / 3000 nm	Ballast tanks (SBT)	0 nm	0.13	0.34
		100 nm	0.26	0.50
	Cargo tanks (COW)	0 nm	0.09	0.35
		100 nm	0.13	0.40
Med / 5000 nm	Ballast tanks (SBT)	0 nm	0.13	0.34
		100 nm	0.26	0.50
	Cargo tanks (COW)	0 nm	0.11	0.41
		100 nm	0.15	0.45
High / 10000 nm	Ballast tanks (SBT)	0 nm	0.13	0.34
		100 nm	0.26	0.50
	Cargo tanks (COW)	0 nm	0.14	0.55
		100 nm	0.18	0.60

Table 4.7: Estimates of transport costs for a range of project parameters[13]

Table 4.7 and the analysis of chapter 4.3 allow economic comparison of FWBH with dedicated tanker vessels. Table 1.6 (page 16) lists costs of various projects using barge, tanker or water bags, most of which have costs higher than what has been calculated for FWBH. Some, though, have comparative cost levels, such as the proposed trade between Turkey and Israel in 2003 – shipping 50 million tons of water each year for a cost of 0.80 US$/ton. It is not clear, however, if this figure includes all necessary port-side infrastructure – most likely it represents what Israel would pay Turkey for the water, which if true indicates that any infrastructure investments in Israel is left out of the picture. Perhaps more interesting is the 2006 study from Australia concluding that using dedicated ULCC tankers to ship water domestically would have a total cost of 5.48 US$/ton. This figure includes all relevant expenses, including the vessels themselves and the modifications of these. Comparing this with FWBH costs, we get a clear indication that FWBH in fact might be a unique opportunity to ship water at a significantly reduced cost. In those cases where FWBH is theoretically possible there is no doubt that it is much cheaper than using dedicated tankers, as the brunt of operational expenses are carried by the oil importer instead of the water importer.

The most interesting water supply technology to compare with is without doubt desalination. As discussed in chapter 1.3.1, desalination is now the primary means of water supply in large parts of the Middle East. The region also has a large potential for FWBH projects as it is the source of a large portion of the world's exported oil, meaning that in many of the possible FWBH ventures desalination will be the primary competitor. Recollecting Table 1.4 listing desalination costs, we see that depending on salinity of the feed water, size of plant and type of power source used costs range from 0.28 USD/ton to as much as 13.75 USD/ton. The scheme proposed and analyzed in chapter 4.3 supplies a total of 35 million tons each year, or 100,000 tons per day, at a cost of between 0.83 and 1.16 USD/ton. Comparing this with the desalination cost estimate table it is clear that FWBH can compete and in many cases be cheaper. Only large scale, conventionally powered plants fed by brackish water can reach costs so low that FWBH cannot compete. This is, however, only valid when extensive infrastructure development is required and simultaneous oil and water handling in port is not possible. If the opposite is true FWBH costs are virtually zero.

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[13] The table assumes water and oil load/unload speed is fixed at 20,000 m^3/hr, no simultaneous handling of cargo, 14 days of offhire per ship per year. All calculations are for a VLCC of 300,000 deadweight tons.

It should be noted that the estimated costs in the specific scenario in chapter 4.3 are strictly theoretical. Forecasting expenses across the whole logistical chain for such a novel project is difficult, and consequently the figures arrived at are quite uncertain; especially for the port side elements. What is clear, however, is it that it is expensive to develop the infrastructure required when developing a fresh water source. In the scenario analyzed here infrastructure accounts for between 50 and 85 % of total costs. The amount of fresh water supplied annually is 35 million ton, which is about 3.5% of the sum weight of crude oil exported from the Middle East in 2007(81). It is likely that expenses could be lowered considerably with exploiting of economies of scale and if some infrastructure already is in place for other purposes. Transport costs will nevertheless not be affected directly by the scale of the operation, but varies with size of vessel and other operational parameters.

5 POLICY AND CONTRACTS

The preceding chapters have concluded that freshwater backhauling is feasible, both technically and economically. Several reports from the previous three decades also arrived at the same conclusion, even when the tanker fleet was technically less suited for the purpose. Why then, has there never been any large scale trade of water by the means of FWBH? In this chapter we discuss the common contractual agreements which facilitate tanker shipping as well as relevant international and national policy. Current state of affairs is reviewed and the impact of legal framework and normal business practice in the tanker market upon the facilitation of FWBH is examined.

5.1 CONTRACTUAL ARRANGEMENTS FOR FWBH

Although the concept of FWBH is not new, the fact remains that little to none precedent exists with regards to contractual aspects. All contracts for the shipment of crude oil will be subject to rules which affect the viability of backhauling freshwater. In this chapter we consider which type of contracts is suited for the purpose of freshwater backhauling and uncover chief issues that would have to be resolved.

The contract between shipowner and shipper is called a charter-party. Creating a contract for the marine transport of goods is very complicated, as the contract must take into account almost any possible event that might occur, such as delays, groundings and break downs. The shipping industry therefore uses standard contracts. The chief categories of contracts are explained below.

VOYAGE CHARTER

A voyage charter is an agreement under which the shipowner agrees to transport a specified amount of cargo from port A to port B with a specified ship, for a negotiated price per ton. The terms will be set out in a charter party. The ship is hired for a single voyage or a series of single voyages (*consecutive voyage charter*), and the shipowner or manager retains full control of the management of the vessel itself. The voyage charter-party is often used for cargoes destined for the spot market. For the crude oil trade, freight rates are normally set as a percentage of the applicable World Scale rate; the percentage depends on spot market conditions. Shipowners operating under single voyage charter have to deal with uncertainty and volatility, and as such it is difficult to imagine such charters being the principal instrument in any long term water trade agreement. Consecutive voyage charters, however, provide more predictability as one knows where the ship(s) will be some time in the future and will therefore be slightly better suited for the task. Of course, this assumes that a good level of stability is required in terms of the amount of water to be transported per day, month or year.

If a more speculative water trade is desired or deemed more economical or practical the voyage charter-party seems quite well suited for the purpose, especially if freshwater unloading facilities could be made available in the majority of oil exporting ports in the country wishing to import water. The voyage charter is more sensitive to market fluctuations than the other forms of contract, and as such not a viable option when the backhauling operation would involve deviating large distances or employing high load factors; see Figure 4-7 and Figure 4-6, page 64. In trades where the backhauling operation is heterogeneous, i.e. involving many different sources where water can be loaded, different ship types and variation in other operational parameters, voyage charters would seem ideal and a dynamic spot market for water could possibly materialize. However, as shown in the abovementioned figures fluctuations in oil freight rate would rapidly alter what freshwater loading ports it would be economical to visit, leading to a severe level of uncertainty for the potential water exporting ports, thereby reducing the quantity of ports aiming to set themselves up for water export.

Consequently, the voyage charter could be used for backhauling water, but a special branch of FWBH would be the result; one where daily water supply in the oil export port(s) cannot accurately be predicted and where only the freshwater exporting ports located close to main tanker routes can participate.

CONTRACT OF AFFREIGHTMENT

The contract of affreightment (or CoA) differs from a voyage charter in that the shipper or charterer is not directly involved in the operational decisions pertaining to what kind of vessels to employ, and how they should be used. For instance, a shipowner agrees to transport a predefined amount of cargo from A to B within six months, with shipments evenly spread out over the period. The contract allows the shipowner to utilize his fleet in more or less the way he wants to solve to task, with the resulting reduced operating expenses benefiting both parties. CoAs are frequently long term contracts, and can in many ways be considered as industrial shipping as the sole purpose is to ship a given amount of cargo at the lowest possible cost. This type of contract is common in the dry bulk sector, and not frequently used in crude oil shipping (82 pp. 183-185). However, CoAs would be superbly suited for a FWBH venture due to the stability and inherent optimization incentives. For this sort of agreement to “catch on” in the crude oil sector negotiations would most likely have to be initiated, between the oil exporting country, oil companies and oil importing governments. A well thought out long term contract could provide benefits to all parties. First, the oil exporting country is supplied with relatively cheap and environmentally friendly freshwater. Second, the oil importing country receives compensation in the form of profit on water exported, cheaper oil or more secure long term oil import contracts. Third, the oil company is endowed with a secure long term contract, possibly higher profits from the backhaul cargo and – given recognition of freshwater ballasting in MARPOL – a simple and economical method of handling future ballast water regulations.

TIME CHARTERS

In a time charter the shipowner retains control of vessel management only, with the charterer assuming operational control. During the specified time, which can range from a single voyage to several years, the charterer directs the vessel and pays all voyage expenses. The owner pays fixed operational expenses and receives a fixed daily or monthly charter rate. Time charters are often used by governments or oil companies for a prolonged duration and due to predictability would therefore be suited for long term contracts for the delivery of freshwater, given that suitable contracts can be negotiated. Time charters are not as common as they once were in crude shipping[14], and governments in both oil exporting and oil importing countries would have to involve themselves to provide shipping companies with incentives for changing the way they manage their fleets.

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[14] In 2006 time charters represented about 25 % of the independent tanker fleet in terms of deadweight, with the remaining 75 % trading on the spot market (79 p. 185).

BARE BOAT CHARTER

With a bareboat charter the charterer takes full operational control of the vessel, and the owner is not involved in the management of the ship – for him the ship is just an investment. Bareboat charters are often used by oil companies who require the use of tankers but do not want to own their own ships. Ships on bareboat charter can be used in any of the abovementioned contracts, with the bareboat charterer in practice acting as owner, and thus all of the above is equally valid for the bareboat charter.

BILL OF LADING

A bill of lading is issued to the shipper when the cargo is loaded onboard the vessel. It serves as a receipt, a document of title (ownership) of the cargo and evidence of the contract of carriage. A bill of lading issued for freshwater to be backhauled places a burden on the shipowner or manager to deliver the correct amount of water, with the specified quality. Such a bill of lading would likely need to be adapted to the special circumstances of FWBH, specifying liability considering any deviations in amount and quality that might occur due to a number of reasons.

5.1.1 SOME CONTRACTUAL ISSUES

One legal issue relevant to the FWBH concept is who will be responsible for the ballast. No matter if the water is loaded in cargo or segregated ballast tanks, the ship must be loaded with enough ballast to preserve seaworthiness. Powles (1983) states that the case of Towse v. Henderson (1850) provides that as long as the (ballast) cargo does not occupy more space than the ordinary ballast would and it does not cause damage to the charterer's cargo there is nothing preventing the shipowner from taking on ballast which doubles as a commercial viable cargo (83). This, of course, applies if the freshwater is loaded on the owner's initiative and not the charterer's. If freshwater is loaded as ballast on the charterer's behest it would be important to note that it is the owner's right to demand sufficient ballast is loaded to preserve the vessels seaworthiness. As such the charter-party should stipulate that the charterer must load a sufficient amount of freshwater.

In the case of voyage charter, a special case arises if he shipowner directs his vessel to deviate to load freshwater as backhaul cargo without the involvement or permission of the charterer. This could for instance happen if the shipowner wants to earn additional profit by hauling water back and still feels he can solve the oil shipping task. No immediately identifiable issues arise if the ship can load water in the same port where oil is discharged, however when a deviation from the route agreed upon in the contract it would be considered a serious breach of contract. This is primarily because a deviation introduces new hazards which the shipper or charterer has not been given the opportunity to take into account – which he for instance could do by acquiring additional insurance coverage. Should the cargo suffer damage during an illegitimate deviation the shipowner will often, depending on applicable law, be imposed with unlimited liability (84 p. 289).

The legal principle of *general average* is a part of maritime law which states that all parties concerned must share the expenses in the event where a part of the ship or cargo must be forfeit to preserve the ship and/or the remainder of the cargo. General average is incorporated into most charterparties through the York Antwerp Rules. When freshwater in the form of ballast also serves a commercial purpose it will be subject to these rules. This entails that if the master has to jettison freshwater to lighten the ship in case of grounding, or must load seawater ballast to increase stability and in so doing contaminates the freshwater, the owner of the cargo (freshwater) is liable to contribute to the resulting economic loss (83).

5.1.2 CONCLUSION

As freshwater backhauling with oil tankers remains a concept on the drawing table, there is no avoiding the development of new rules and a contractual framework to preserve the interest of all parties in the event of a realization of the idea. It is our view that for a large scale FWBH project to materialize a combined effort is required, involving national authorities, shipping companies, port authorities and oil companies. The primary reason for this is not that the development of a contractual framework demands it, but rather that all these parties must take part in and benefit from the project.

One could envision two entirely different FWBH market systems. One in which freshwater is traded on the spot market and shipowners take on backhaul cargoes at their own initiative, depending on market conditions. In this case current crude shipping contractual standards would not require much modification. The other case is one where governments take on a more active role and crude oil shipping takes a step “backwards” toward industrial shipping. This would ensure more stable market behavior, and would allow arid countries to increase dependency on freshwater imported with ships.

To summarize, it does not seem like resolving contractual issues in shipping would prove a prohibitively large obstacle. Quoting Powse (1983): ”[...] the carriage of FWB [Freshwater Ballasting] basically fits into the existing legal framework of the law of carriage and the problems are in the main technical rather than conceptual.”(83)

5.2 REGULATION OF INTERNATIONAL TRADE IN BULK WATER

International trade in freshwater is for the most part represented by virtual water. Large scale international bulk trade agreements have rarely been carried out and most large scale water diversion or transport projects remain regional or national. There is little doubt that the reason for this is not limitations in terms of technology or possible cross-border projects. Rather, it can most likely be attributed to a resistance to trade away the most precious resource available to us, and a resistance to turning water into a commodity to be traded alongside oil, minerals, timber and other goods. There is a growing concern in countries with abundant freshwater that if international trade becomes “normal” and water scarce regions become dependent on bulk imports, they will be faced with demands that their resources be tapped “for the greater good”, taxing their own environment and people.

In the context of this report, the interesting element is if this resistance is critical for the viability of freshwater backhauling, or if FWBH itself provides a way of allowing international trade of freshwater in bulk whilst bypassing some of the issues mentioned above.

INTERNATIONAL REGULATIONS

Let us first review the current state of regulation of international trade in bulk water. Some examples of projects proposed or carried out are referred to in chapter 0; beyond the occasional large scale operation due to drought or other emergencies international out-of-basin transfers remain few and far between. We can also conclude that there exists little – if any – legal precedents in terms of how to handle international trade of freshwater in bulk(85). However increased commercial pressure to allow export of freshwater has led to recent, interesting developments, specifically in North America.

In 1995 the British Colombia (BC) state government in Canada issued a ban on bulk water export in the face of imminent commercial projects which would ship BC water to California using converted oil tankers. The California-based company Sun Belt Water Inc. sued the Canadian government in 1998, under the North American Free Trade Agreement (NAFTA) chapter 11, as the export ban destroyed the Sun Belt Water tanker export scheme. The claim remains unresolved at the time of writing, but we examine the regulatory backdrop in order to get a picture of what difficulties that affect legislation on bulk water trade.

Regulating international trade and significant in this case is both the World Trade Organization (WTO) General Agreement on Tariffs and Trade (GATT) and the NAFTA. GATT is the predecessor of the WTO itself, but is still active as a part of the WTO regulatory framework and serves as the basic structure for governing international trade between WTO member countries. Of special importance in the case of bulk water trade is the GATT Article XI, section 1:

> *No prohibitions or restrictions other than duties, taxes or other charges, whether made effective through quotas, import or export licences or other measures, shall be instituted or maintained by any contracting party on the importation of any product of the territory of any other contracting party or on the exportation or sale for export of any product destined for the territory of any other contracting party.(86)*

In practice this article works by preventing governments from restricting or banning the export of freshwater in bulk once this type of trade has commenced and bulk water is considered a tradable good, though it does allow tariff measures. Although, or perhaps because, legal precedent does not yet exist some environmental organizations and other actors – likely including the Canadian government – worry that once trade in bulk water has begun it will be difficult or impossible to stop. Governments may be exempt from Article XI by way of Article XX: General Exceptions:

> *Subject to the requirement that such measures are not applied in a manner which would constitute a means of arbitrary or unjustifiable discrimination between countries where the same conditions prevail, or a disguised restriction on international trade, nothing in this Agreement shall be construed to prevent the adoption or enforcement by any contracting party of measures:*
>
> *[...]*
>
> *(b) necessary to protect human, animal or plant life or health;*
>
> *[...]*
>
> *(g) relating to the conservation of exhaustible natural resources if such measures are made effective in conjunction with restrictions on domestic production or consumption;(86)*

Article XX (b) and (g) provide that if placing restrictions on water trade is required to preserve people or the environment, or if the water resource in question is not renewable, Article XI will not apply and bulk water export may be restricted or banned. The question of whether or not a country can enforce export restrictions due to environmental protection remains in debate in the WTO. There are also uncertainties as to how to decide if a water resource is renewable or not; traditionally water resources have been viewed as renewable, but as more and more rivers, lakes and aquifers dry up or become contaminated it has become evident that when mismanaged, freshwater can be exhausted.

The NAFTA is a trade agreement between the U.S., Canada and Mexico. In many ways it can be seen as an extension of WTO in North America. The aforementioned NAFTA Chapter 11, under which Sun Belt Water filed the claim against the Canadian government, provides *"a mechanism for the settlement of investment disputes"* (87). It disallows a member government from nationalizing or expropriating an investment, in this case freshwater, in such a way that the company's future profits are diminished or destroyed. In this way it works as yet another paragraph that makes it difficult to restrict water trade once it has commenced.

The most important issue to resolve, however, is whether bulk water can be regarded as a tradable good at all. If it is *not*, it will not fall under WTO regulation and can be protected from exploitation by governments. It is argued that as United States, and most other countries (88), customs rules already include classification of water *of all kinds* it should be regarded as a tradable good, since only tradable products are dealt with by customs[15]. The modern debate over whether or not water can be regarded as an economic good was sparked in 1992 in Dublin, Ireland, when during the International Conference of Water and the Environment (ICWE) participants from over 100 nations concluded that *"Water has an economic value in all its competing uses and should be recognized as an economic good"*(85).The now famous Agenda 21, springing from The United Nations Conference on Environment and Development in Rio de Janeiro, 1992, adopted this idea with some modification: *"Integrated water resources management is based on the perception of water as an integral part of the ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its utilization"*(89). Although the UN has recognized that water can be an economic good their position is not that is a good of "strictly" economic nature; rather, Agenda 21 goes on to state that *"water resources have to be protected"*. It is Canada's position, and the basis for the 1995 ban, that water is not a tradable good or product, and have defended this position unwaveringly, stating that "*Nothing in NAFTA or in any of Canada's international trade agreements prevents us from protecting our water. These agreements do not create new obligations for us to sell our water, nor do they limit our ability to adopt laws for managing our own water resources"* (90).

When evaluating the viability of freshwater backhauling with tankers it is of course vital that there exists a legal framework that makes international bulk water trading possible. A likely reason that cross-border water transfer projects, although ever new projects are proposed, never seem to rise from the drawing table is that no one is sure what rules apply. The start-up of a major scheme would likely involve studies of environmental and international trade law as well as negotiations on an intergovernmental level, both of which could prove lengthy and costly. With this uncertainty in mind it is not difficult to understand that investors and companies hesitate. It is also very difficult to ascertain what ramifications the first large scale venture might have on the status of freshwater, making governments equally hesitant in giving their support to water export schemes.

The freshwater debate, including the issues of commoditization of water and international water management, should perhaps be regarded as one of the most important debates in history. It is unlikely that clear answers to the issues raised above will present themselves in the near future, but increasing commercial pressure coupled with increasing water scarcity could push large international out-of-basin transfer projects into action, most likely within this decade. If this happens legal clarifications will inevitably materialize, and in line with the GATT water will be defined as a tradable good covered by existing international trade legislation.

While what has been discussed here considers water in terms of globalization and free trade, a different approach to develop a legal framework for cross-border water transfer projects is *integrated transboundary watershed management*. The EU Water Framework Directive, put forth in 2000 and part of the EU's increasingly extensive body of water legislation, aims to increase cooperation between member states in managing water resources. It is not unlikely that Europe will see extensive water diversion projects in the not too distant future, with plans already proposed for a *European water network,* to facilitate transfer of water from North European rivers and the Alps to Southern Europe countries (91).

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[15] The Harmonized Tariff Schedule (HTS) is a system for classifying tradable goods for import to the United States. Import of "other waters" is duty free at the time of writing and the 2201.90.00|00 HTS code reads*: "Other Waters,* [not] *including natural or artificial mineral waters and aerated waters, not containing added sugar or other sweetening matter nor flavored; ice and snow" (100 pp. IV 22-3)*

It is evident that it would not be straight forward to initiate a FWBH venture. Compared with dedicated water carrying tankers though, FWBH does come with some benefits which might make it easier to accept by authorities and the general public. A FWBH scheme could be seen as a way of using the ballast voyage, which in itself produces no value, to improving the environmental efficiency of water supply given that alternative available water supply techniques are inferior. Not only would the environmental footprint of supply from FWBH be less than, say, dedicated tankers or perhaps desalination, but traditional ballast water issues, such as marine organism translocation, would be mitigated – this is further analyzed in the next chapter. This way FWBH takes an existing trade and provides added value, whereas novel projects using dedicated tankers might be seen as more speculative as it is not as easy to identify the environmental benefits.

6 ENVIRONMENTAL

The analysis of FWBH has now been done for technical and economical feasibility, with technical modifications and costs having been established. However there is another important factor to be considered during the conceptual phase, which covers the environmental impact and compares FWBH in terms of long term environmental influence with other methods of supplying/producing water, like desalination. This gives a better understanding of sustainability versus feasibility of the concept. The impact on environment from FWBH can be divided into two categories; one which encompass air pollution and predominantly deals with greenhouse gas emission, and one category which considers pollution of the marine environment, including transfer of invasive species and harmful discharges from freshwater ballast tanks if any. We compare FWBH with desalination and dedicated tankers for transfer and supply of freshwater within these two categories.

The concept of replacing seawater ballast by freshwater for useful consumption can broadly be described as a “green technology” as in theory there would not be any additional emissions from the ship for transporting freshwater in case of freshwater and oil ports being the same. The only significant CO_2 emissions will be generated by the pumping stations in the loading port. However, deviating from the existing oil trade routes for back hauling freshwater can cause significant emission additions and forms an important emissions related constraint in case of different freshwater and oil ports on the trade route.

The greatest environmental benefit from using FWBH for oil tankers is the mitigation of harmful effects from carrying invasive species in the seawater ballast. The invasion of certain marine species and its adverse impact on environment, ecology and economy has been proven to be immense. *The United States Environmental Protection Agency (EPA) has estimated that invasive species are responsible annually for $100 billion in damages in the United States* (U.S.) (Cangelosi 2002-2003: 69)(92)

6.1 COMPARING FWBH WITH DESALINATION

To maintain a level playing field in the comparison of FWBH and desalination of seawater emissions from pumping (in case of FWBH up/downstream activities) and treatment (for FWBH and pipeline both) have been taken in to account for different volumes of freshwater supply. Emissions from construction of desalination plant, oil tankers and manufacturing of pipes have not been included in the analysis. Comparison of the impact on the marine environment by desalination and FWBH is done on a cumulative and long term basis such that any environmental damages by accumulation of harmful ingredients in the discharges to ocean are also covered.

6.2 GHG EMISSIONS

Countries in the Middle East have one of the highest per capita CO_2 emissions in the world, Qatar, United Arab Emirates, Kuwait and Bahrain are the top 4 emitters of CO_2 in per capita terms in the world (93). This may not be surprising considering the fact that these countries have a dense network of desalination plants, all of which use fossil fuels. Using FWBH even for relatively small volumes of 1-2 million tons per annum can possibly help curtail sizeable amount of CO_2 emissions. As explained in Chapter 1.3.1 desalination can be carried out using reverse osmosis or multi-stage flashing process, which utilizes different quantities of power and hence has different emission coefficients for producing a given volume of freshwater.

6.2.1 METHODOLOGY

Comparison of emissions from desalination, FWBH and shuttle tankers has been done by evaluating kilograms of CO_2 produced per ton of freshwater yield.

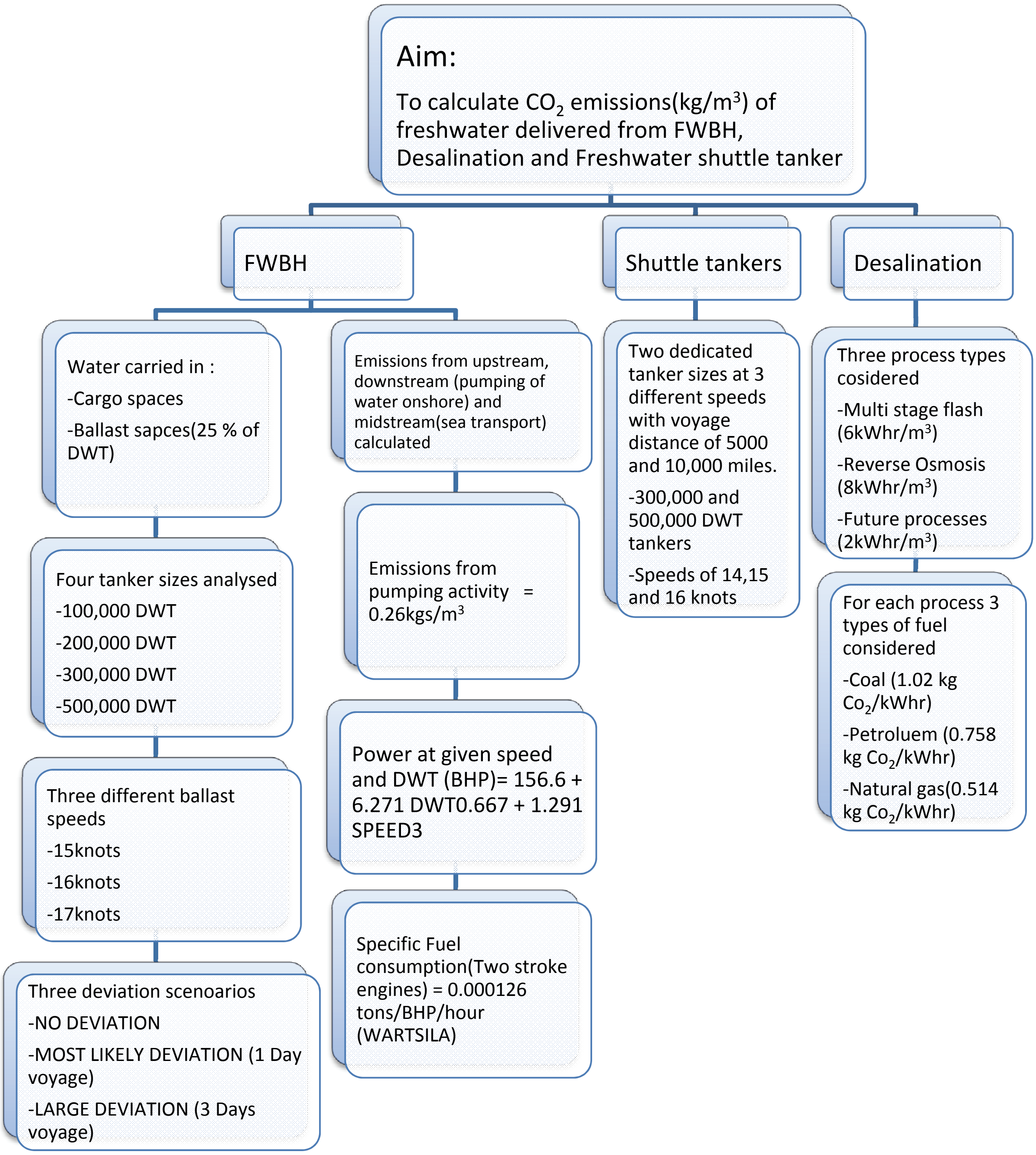

Figure 6-1: Approach to environmental analysis

Process Type	Fossil Fuel type	Emissions (kg CO_2/m^3)
Multi-Stage Flash(MSF)	Coal	6.1
	Oil	4.5
	Natural Gas	3.1
Reverse Osmosis (RO)	Coal	8.1
	Oil	6.1
	Natural Gas	4.1
Future desalination processes	Coal	2
	Oil	1.5
	Natural Gas	1

Table 6.1: Desalination CO_2 emissions

The CO_2 emissions from a desalination plant which works by MSF or RO lie between 3-8 kg/m^3 depending upon the type of fuel used. In comparison, dedicated freshwater tankers will have a minimum CO_2 emission (among all scenarios considered) of 11.5 kg/m3, which is the highest amongst the three methods of freshwater supply analysed. The results from FWBH for different scenarios are shown in Table 6.2. It is interesting to note that FWBH in ballast spaces even for medium deviation time/distances produces more CO_2 per m^3 in comparison with desalination, except when using a ULCC of 500,000 DWT. When freshwater is carried in cargo spaces medium deviations become less important and even large deviations of 3 days is an environmentally efficient option compared to desalination, in case of a ULCC carrying freshwater as cargo. These results are interesting as they present facts which go against the natural assumption from the outset that freshwater backhaul by VLCC/ULCC would most likely be a "green" and less emission producing option compared with desalination, at least for small deviations (where deviation time<10% of voyage time).

Deadweight (DWT)	Deviation (Days)	Freshwater in ballast tanks Emissions (kg CO_2/m^3)	Freshwater in cargo tanks Emissions (kg CO_2/m^3)
100000	0	**0.3**	**0.1**
	1	7.2	**1.8**
	3	21.2	5.3
200000	0	**0.3**	**0.1**
	1	3.7	**1.3**
	3	10.7	3.8
300000	0	**0.3**	**0.1**
	1	3.6	**1.1**
	3	10.3	3.2
500000	0	**0.3**	**0.1**
	1	**2.8**	**0.7**
	3	7.8	**2.6**

Table 6.2: FWBH CO_2 emissions

Comparison of emissions from desalination and FWBH for a supply of 35 million tons per annum using the most likely scenarios for both processes shows that the saving in emissions can range from anywhere between 4,500-35,000 tons of CO_2. The most likely scenario for desalination is assumed to be a MSF plant using oil as fuel. For FWBH water is assumed to be carried in ballast spaces only and comparison is done for a combination of different sizes of tankers at 15 knots and medium deviation (1 day). Using only ULCC`s to satisfy the given demand results in the least emissions from FWBH and maximum difference of 35,000 tons compared with desalination. In the combination scenario the smallest tanker (200,000 DWT) was assigned to carry 50% or 17.5 million tons of freshwater and the remaining demand distributed evenly between 300,000 DWT and 500,000 DWT tankers. The emissions in this scenario were significantly higher with the saving in emissions from desalination reduced to 4000 tons of CO_2.

Looking into future processes and technical advancements in desalination technology it is expected desalination can power demand can be lowered to around 2 kWhr/m^3 in the future, which is around one-third of what has been selected as the most likely power consumption for analysis in this chapter. FWBH in none of the scenarios was found to better than desalination in terms of emissions for these estimated future energy consumption values.

6.3 MARINE DISCHARGES

The harmful effect from desalination plant discharges has already been discussed in chapter 1.3.1. Clearly they present an important environmental challenge and intakes/discharges from desalination plants in the Middle East has been cited as one of the major reasons for the degradation and destruction of the ecosystem by high salinity water mixed with copper, chlorine and anti-scalants discharge in to the ocean (28). For FWBH we focus mainly on how FWBH can be an easy and effective method to reduce or eliminate ballast water problems if applied on a large scale in world trade.

The IMO Ballast Water Convention (BWC) is currently ratified by a mere 22 states, representing about 23 percent of the merchant fleet tonnage. For the convention to go into force at least 30 states representing 35 % of world`s merchant tonnage have to ratify. The BWC standards are to be implemented on all vessels constructed after 2009 (BWC 2005: Regulation B3); vessels built prior to 2009 have until 2014-2016 to comply, depending on their size (BWC 2005: Regulation B3). Thus once ratified all vessels would have to undergo changes to comply with BWC by installing ballast water treatment and management systems onboard. Fundamentally these systems utilize one or more of a range of solutions, like heat, chemical, filtration or ultraviolet/sound waves to kill the marine organisms in the water.

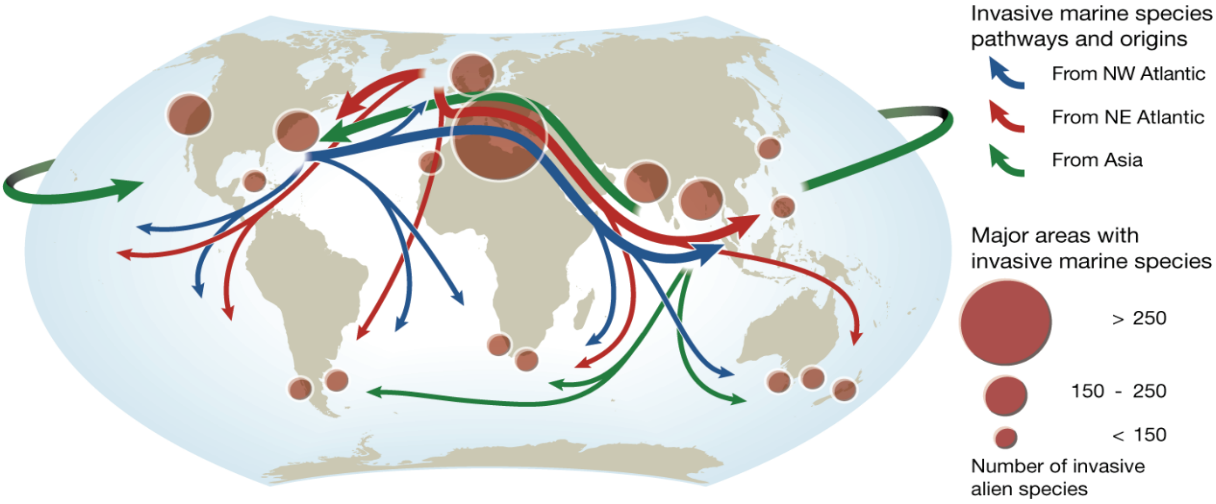

Figure 6-2: Major areas of invasive aquatic species in the world **Source: (94)**

Replacing seawater with freshwater ballast would result in stopping the transfer of one species of marine organisms to another location completely. Also, the need to install ballast treatment facilities onboard can be waived for tankers which will operate on routes where freshwater ballast is guaranteed for the lifetime of their operation. In practise, though, the oil tanker would need to take in sea water ballast for some duration of the voyage where it deviates from the normal trading route to load or unload freshwater ballast, thus making it necessary to install ballast water treatment system onboard when the BWC comes into force. The ballast water convention does not mention or provide any provision for exemption for ships which load and unload ballast within a bio-region. Defining and demarcating different ecosystem and bioregions around the oceans of the world with uniform aquatic bio-life is a complex but necessary in case of freshwater becoming a popular ballast medium. Ships deviating to load or unload freshwater within a particular marine eco-system can be exempted to perform ballast water treatment procedures. Further research is required to ascertain if loading and unloading untreated ballast water within a marine ecosystem presents any damage to the environment.

Thus there lies potential in FWBH to completely eliminate the harmful effects of carrying sea water ballast even while carrying seawater ballast for short durations within a marine ecosystem.

6.4 CONCLUSION

As shown FWBH is not always the environmentally best option in terms of GHG emissions for supplying freshwater when compared with desalination. Future improvement and advances in desalination technology improves the efficiency of desalination and can make it a lesser GHG emitting option than FWBH. It is important to note that the quantity of water transported from FWBH is only supplementary and in no way can become the major source of freshwater for any oil rich port/city and thus a small increase in CO_2 emissions can be conceivable if that would result in mitigating other large environment damages like invasive species from sea water ballast. The location of freshwater ports should optimally be in the same marine ecosystem area as the oil ports so as to allow the oil tankers to use seawater ballast without much/any treatment to be performed on the sea water ballast. Further research and studies need to be done to assess this effect. The environmental advantages like elimination or large scale reduction of ballast water related environmental damages thus take greater prominence for deciding if FWBH should be considered as an environmentally friendly idea.

7 CONCLUSION

This report has analyzed the concept of using oil tankers' return space to carry freshwater as return cargo to arid, oil exporting countries. From a technical and practical point of view it has been shown that the concept is feasible. Port-side infrastructure development of a certain scale would be required along with minor vessel modifications, but the technology exists and is well known.

It has also been shown that FWBH can in some cases compete with other means of water supply on an economic basis, especially if one makes possible simultaneous oil and freshwater handling in port, in which case transport costs would be virtually zero. If the water-importing actor is a country such as Saudi Arabia or Kuwait, it is likely that a cost comparison with desalination is a deciding factor when considering FWBH. It is clear that both desalination and FWBH costs vary greatly depending on several factors, such as water quality requirements, scale of operation, capital costs (infrastructure development) required and location of point of water consumption. If there is little existing water handling infrastructure in and near the relevant ports, FWBH is likely more expensive than large scale desalination powered by fossil fuels. On the other hand, if the desalination plants considered are of medium or small size and powered by renewable energy FWBH would in all probability be substantially cheaper.

Cost is not the only element that should be considered, especially considering the ever increasing focus on negative environmental impacts from human activities. If FWBH can beat desalination powered by RE on cost, it probably cannot beat it on GHG emissions. In fact, FWBH, although less GHG intensive than dedicated tankers, is far from always better than desalination when it comes to CO_2 emissions. Just like the economics, the environmental effects from FWBH vary greatly with the specific operational modes chosen.

To summarize, using oil tankers return space to transport freshwater is feasible and a "smart" thing to do if the following aspects are considered:

- Simultaneous handling of oil and water in both ports should be a priority
- Minimize distance to deviate to acquire water, preferably get it in oil unloading port
- If the two above conditions are met, use only ballast tanks to carry water (20-30% DWT)
- If emissions is a big factor to consider, use as big ships as possible
- If directly competing with desalination, accurately quantify economic and environmental benefits from FWBH to oil exporting actor
- Authorities needs to play a leading part in the FWBH contracts, should be involved from the start

FWBH is perhaps not as great an idea as it might seem at first glance, with clear limitations both in terms of costs and environmental impact, and quite a few conditions must be satisfied before it becomes a truly sensible concept in the eyes of commercial and public actors alike. But there is still no doubt that if done correctly it can be a very cheap way of lowering GHG emissions, increasing water supply and mitigating ballast water management issues. Recognizing this, the obvious question becomes: Why has it not been realized before? Why hasn't there been even one single trial project, and why has it not received greater attention from governments and IMO?

The most obvious beneficiary for a freshwater backhauling operation using oil tankers is the Middle East, where Saudi Arabia and Kuwait has the biggest potential due to their heavy reliance on desalination and the high volume of tankers trading in their ports. Trygve Meyer, former vice president at Intertanko and author of several reports on freshwater transport with tankers, concludes that one chief reason why Saudi authorities have been unwilling to initiate marine freshwater import projects is a strong desalination industry lobby (65).

While this may be part of the problem, it is our opinion that the foremost issues are that potential water exporters are afraid their freshwater will be "commoditized" and that potential water importers are not convinced benefits from FWBH is worth the effort. As for the shipowners, there is no reason to doubt that their focus will remain on earning money in the future as well, and they will in all probability be ready to carry freshwater as return cargo should it become possible. The fourth piece in the puzzle, ports and port authorities are, like shipowners, at the mercy of governments. The "puzzle" is shown in Figure 7-1 below.

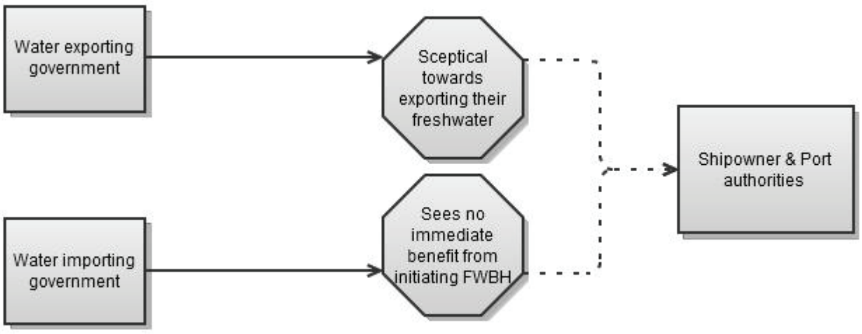

Figure 7-1: Barriers preventing FWBH from being realized

It is evident that some form of transnational initiative is needed to get a FWBH trade going. The below figure illustrates – in a very simplified manner – one way of breaking the barriers, through involvement from WTO and IMO.

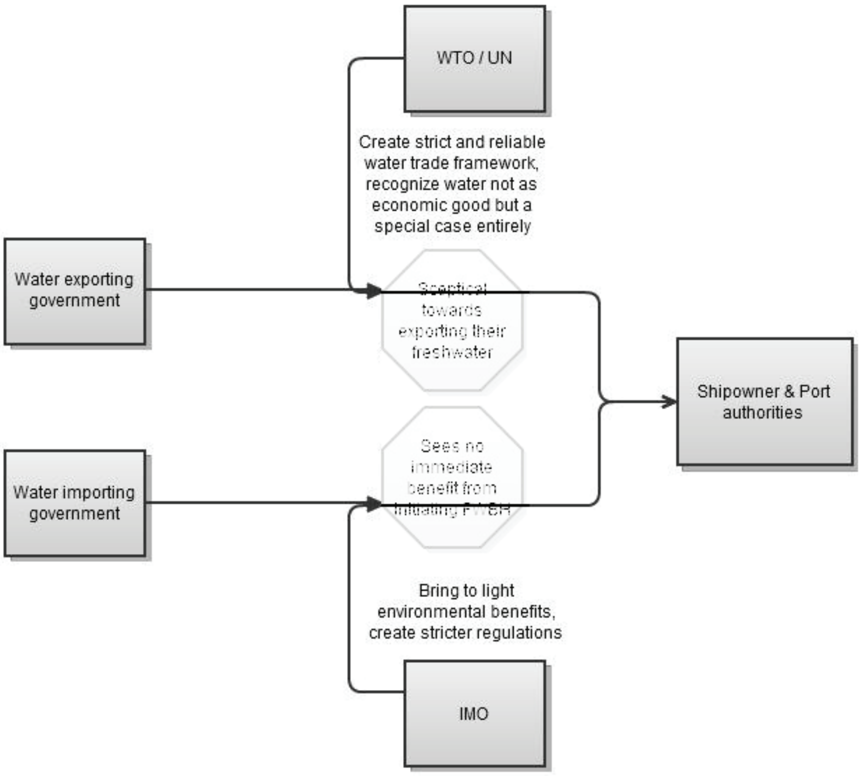

Figure 7-2: Transnational agency involvement breaking barriers

The focus the topic of water trade by tankers received in the 1980s was due to volatility and low rates in the crude oil market. Today, a renewed attention would have to be powered primarily be environmental concerns. By highlighting the environmental drawbacks of desalination, which include not only large GHG emissions but also negative effects on surrounding marine ecosystems, it should be possible to convince authorities in countries like Saudi Arabia that alternatives must be considered.

These might seem like quite intricate obstacles, with the issue of water commoditization looking like the most substantial problem to solve. With this in mind it is interesting to note that in the 1980s, Canada, Japan and the Netherlands initiated programs to get a freshwater export trade going. Canada has since changed position completely, fiercely defending their right **not** to export freshwater, but Japan and the Netherlands apparently halted their plans due to lack of buyers.

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Figure 7-3: Advertisement in Intertanko publication, 1983 (73)

Things have changed since then, and awareness regarding the difficulties of international trade of freshwater has certainly increased. That is why we believe that more discussion is needed before the idea of exporting freshwater becomes common; common enough to supply a large scale freshwater backhaul trade. Then again, with water scarcity reaching ever higher levels international water trade will more than likely force its way onto the global agenda, as it for instance is doing in Spain and Turkey at the time of writing.

At the time of writing we are witnessing a surge in global awareness of freshwater scarcity and management. In view of the immense growth in population and lack of water in some regions, cross-border freshwater trade might become a necessity. Although not necessarily by way of FWBH, 30 years from now seagoing tankers carrying fresh water may be a common sight.

Almost all previous research into the use of oil tanker return space for the transportation of freshwater was done in the 1970s and 80s; with a focus only on technical and economical aspects the reports published then all concluded that FWBH was a feasible and clever thing to do. The approach opted for in this report 30 years later, we believe, provides new information key for understanding why no one has ever initiated large scale FWBH before, and makes it clear that when analyzing such a concept it is not sufficient to consider it only from the shipowners point of view.

8 SUGGESTIONS FOR FURTHER WORK

Based on the information uncovered in this report, if the goal is to get a FWBH trade going, we believe it should be a priority to get a dialog going between the market actors that would be affected or involved. This means that further research into the topic should be aimed at providing accurate quantitative information about the costs and total infrastructure development requirements, as well as mapping and highlighting solutions to regulatory and contractual problems.

The approach chosen in this report for finding infrastructure costs is very simple, and can easily be improved upon. A more substantial economical comparison with desalination would also be interesting, as it is uncertain how “complete” the cost figures used for desalination are, i.e. if they actually include capital expenses for all relevant infrastructure. We also believe that experiments should be carried out to uncover how the quality of freshwater is affected by being carried and handled in the way it would onboard an oil tanker, as this is information that is difficult to estimate theoretically. Still, technical and practical aspects should be the easiest ones to solve, but it is a in-depth study of regulatory and contractual aspects, preferably carried out by someone educated in the field of law, which would most serve to make FWBH a much more realistic topic than it is at the moment.

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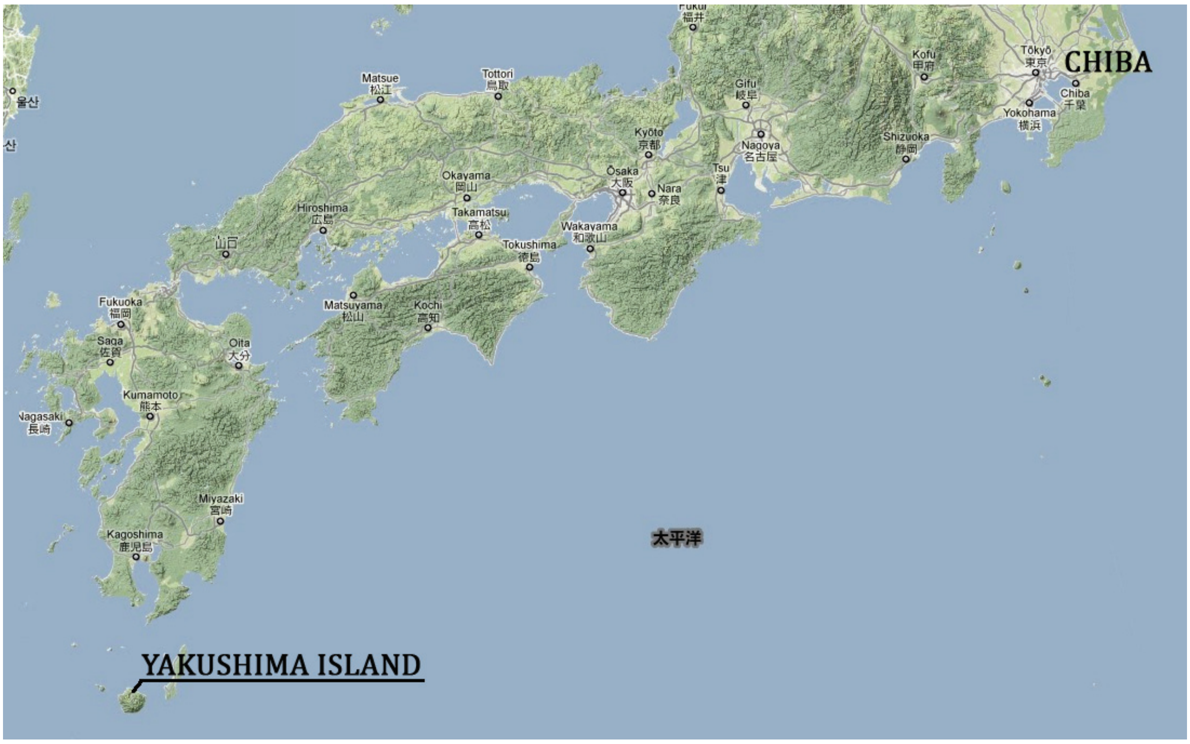
APPENDICES

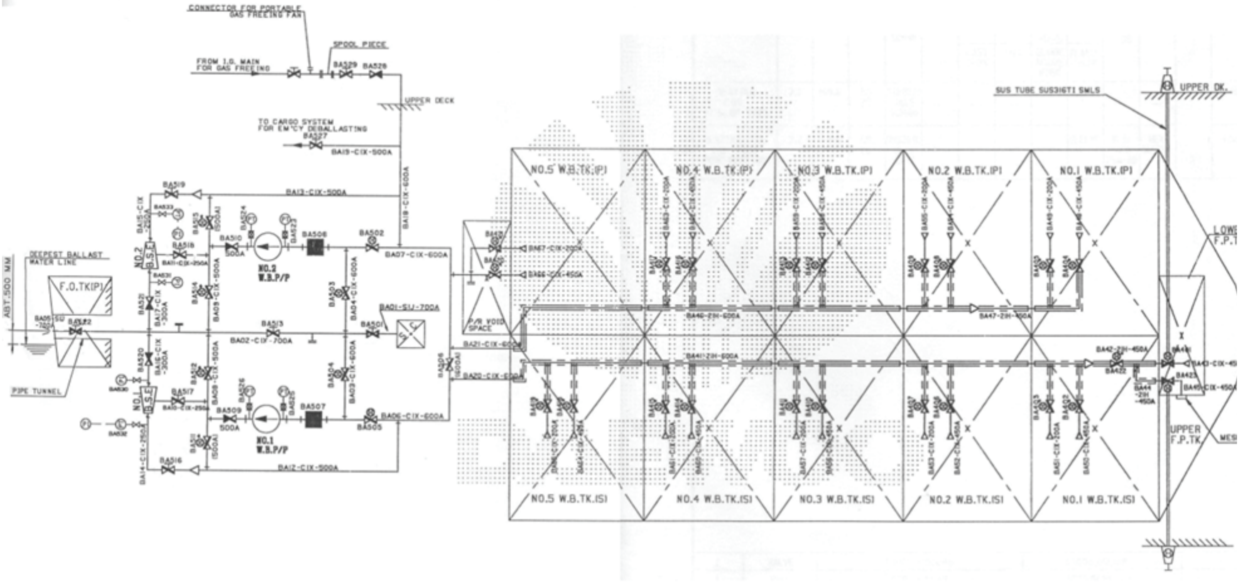
Appendix A) Map of Ras Tanura port

Appendix B) LOCATION OF YAKUSHIMA ISL.



Appendix C) BALLAST LINES OF M/T “BW ULAN”

Ballast tanks arrangement



Ballast tanks capacities

Compartment	Capacities	
	Volume 100% - m3	Volume 100% - MT
F.P. TK (lower)	3 785.3	3 879.9
F.P. Tk (uper)	3 042.2	3 118.2
WB 1 P	8 731.3	8 949.6
WB 1 S	8 731.3	8 949.6
WB 2 P	9 877.1	10 124.1
WB 2 S	9 877.1	10 124.1
WB 3 P	9 965.2	10 214.3
WB 3 S	9 965.2	10 214.3
WB 4 P	9 706.1	9 948.7
WB 4 S	9 706.1	9 948.7
WB 5 P	8 087.6	8 289.7
WB 5 S	8 087.6	8 289.7
E/R P	790.7	810.4
E/R S	790.7	810.4
AFT PEAK	2 110.2	2 162.9
TOTAL	**103 253.7**	**105 834.6**

Loadline information

	Freeboard	Draft	Deadweight	Displacement
Summer	4852 mm	22.023 m	299 324.9 MT	341 097.3 MT
Winter	5310 mm	21.565 m	291 496.3 MT	333 268.7 MT
Tropical	4394 mm	22.481 m	307 156.7 MT	348 929.1 MT
Lighship	23738 mm	3.137 m	0	41 772.4 MT
Normal ballast condition	16900 mm	9.975 m	102 693.5 MT	144 465.9 MT
Segregated ballast condition	16900 mm	9.975 m	102 693.5 MT	144 465.9 MT

Appendix D) DRINKING WATER STANDARDS (WHO)

Element/ substance	**Symbol/ formula**	**Normally found in freshwater/surface water/ground water**	**Health based guideline by the WHO**
Aluminium	Al		0,2 mg/l
Ammonia	NH_4	< 0,2 mg/l (up to 0,3 mg/l in anaerobic waters)	No guideline
Antimony	Sb	< 4 μg/l	0.005 mg/l
Arsenic	As		0,01 mg/l
Asbestos			No guideline
Barium	Ba		0,3 mg/l
Berillium	Be	< 1 μg/l	No guideline
Boron	B	< 1 mg/l	0,3 mg/l
Cadmium	Cd	< 1 μg/l	0,003 mg/l
Chloride	Cl		250 mg/l
Chromium	Cr^{+3}, Cr^{+6}	< 2 μg/l	0,05 mg/l
Colour			Not mentioned
Copper	Cu		2 mg/l
Cyanide	CN^-		0,07 mg/l
Dissolvedoxygen	O_2		No guideline
Fluoride	F	< 1,5 mg/l (up to 10)	1,5 mg/l
Hardness	mg/l $CaCO_3$		No guideline
Hydrogen sulfide	H_2S		No guideline
Iron	Fe	0,5 - 50 mg/l	No guideline
Lead	Pb		0,01 mg/l
Manganese	Mn		0,5 mg/l
Mercury	Hg	< 0,5 μg/l	0,001 mg/l
Molybdenum	Mb	< 0,01 mg/l	0,07 mg/l
Nickel	Ni	< 0,02 mg/l	0,02 mg/l
Nitrate and nitrite	NO_3, NO_2		50 mg/l total nitrogen
Turbidity			Not mentioned
pH			No guideline
Selenium	Se	< < 0,01 mg/l	0,01 mg/l
Silver	Ag	5 – 50 μg/l	No guideline
Sodium	Na	< 20 mg/l	200 mg/l
Sulfate	SO_4		500 mg/l
Inorganic tin	Sn		No guideline
TDS			No guideline
Uranium	U		1,4 mg/l
Zinc	Zn		3 mg/l

Organic compounds

Group	**Substance**	**Formula**	**Health based guideline by the WHO**
Chlorinated alkanes	Carbon tetrachloride	$C Cl_4$	2 μg/l
	Dichloromethane	$C H_2 Cl_2$	20 μg/l
	1,1-Dichloroethane	$C_2 H_4 Cl_2$	No guideline
	1,2-Dichloroethane	$Cl CH_2 CH_2 Cl$	30 μg/l
	1,1,1-Trichloroethane	$CH_3 C Cl_3$	2000 μg/l
Chlorinated ethenes	1,1-Dichloroethene	$C_2 H_2 Cl_2$	30 μg/l
	1,2-Dichloroethene	$C_2 H_2 Cl_2$	50 μg/l
	Trichloroethene	$C_2 H Cl_3$	70 μg/l
	Tetrachloroethene	$C_2 Cl_4$	40 μg/l
Aromatic hydrocarbons	Benzene	$C_6 H_6$	10 μg/l
	Toluene	$C_7 H_8$	700 μg/l
	Xylenes	$C_8 H_{10}$	500 μg/l

	Ethylbenzene		$C_8 H_{10}$	300 µg/l
	Styrene		$C_8 H_8$	20 µg/l
	Polynuclear Aromatic Hydrocarbons (PAHs)		$C_2 H_3 N_1 O_5 P_{1\ 3}$	0.7 µg/l
Chlorinated benzenes	Monochlorobenzene (MCB)		$C_6 H_5 Cl$	300 µg/l
	Dichlorobenzenes (DCBs)	1,2-Dichlorobenzene (1,2-DCB)	$C_6 H_4 Cl_2$	1000 µg/l
		1,3-Dichlorobenzene (1,3-DCB)	$C_6 H_4 Cl_2$	No guideline
		1,4-Dichlorobenzene (1,4-DCB)	$C_6 H_4 Cl_2$	300 µg/l
	Trichlorobenzenes (TCBs)		$C_6 H_3 Cl_3$	20 µg/l
Miscellaneous organic constituents	Di(2-ethylhexyl)adipate (DEHA)		$C_{22} H_{42} O_4$	80 µg/l
	Di(2-ethylhexyl)phthalate (DEHP)		$C_{24} H_{38} O_4$	8 µg/l
	Acrylamide		$C_3 H_5 N O$	0.5 µg/l
	Epichlorohydrin (ECH)		$C_3 H_5 Cl O$	0.4 µg/l
	Hexachlorobutadiene (HCBD)		$C_4 Cl_6$	0.6 µg/l
	Ethylenediaminetetraacetic acid (EDTA)		$C_{10} H_{12} N_2 O_8$	200 µg/l
	Nitrilotriacetic acid (NTA)		$N(CH_2COOH)_3$	200 µg/l
	Organotins	Dialkyltins	$R_2 Sn X_2$	No guideline
		Tributil oxide (TBTO)	$C_{24} H_{54} O Sn_2$	2 µg/l

Pesticides

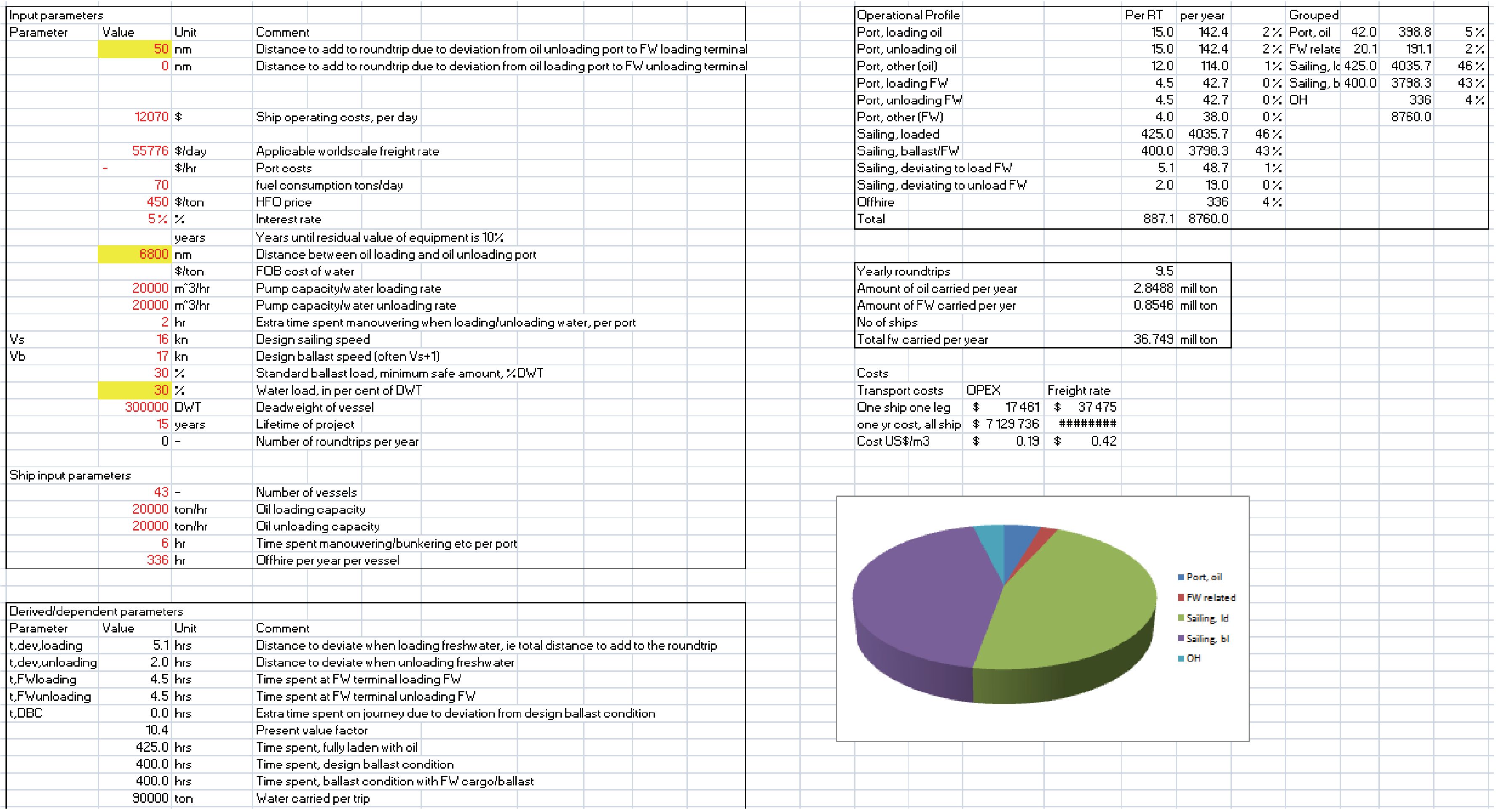
Substance		**Formula**	**Health based guideline by the WHO**
Alachlor		$C_{14} H_{20} Cl N O_2$	20 µg/l
Aldicarb		$C_7 H_{14} N_2 O_4 S$	10 µg/l
Aldrin and dieldrin		$C_{12} H_8 Cl_6$/ $C_{12} H_8 Cl_6 O$	0.03 µg/l
Atrazine		$C_8 H_{14} Cl N_5$	2 µg/l
Bentazone		$C_{10} H_{12} N_2 O_3 S$	30 µg/l
Carbofuran		$C_{12} H_{15} N O_3$	5 µg/l
Chlordane		$C_{10} H_6 Cl_8$	0.2 µg/l
Chlorotoluron		$C_{10} H_{13} Cl N_2 O$	30 µg/l
DDT		$C_{14} H_9 Cl_5$	2 µg/l
1,2-Dibromo-3-chloropropane		$C_3 H_5 Br_2 Cl$	1 µg/l
2,4-Dichlorophenoxyacetic acid (2,4-D)		$C_8 H_6 Cl_2 O_3$	30 µg/l
1,2-Dichloropropane		$C_3 H_6 Cl_2$	No guideline
1,3-Dichloropropane		$C_3 H_6 Cl_2$	20 µg/l
1,3-Dichloropropene		$CH_3 CHClCH_2 Cl$	No guideline
Ethylene dibromide (EDB)		$Br CH_2 CH_2 Br$	No guideline
Heptachlor and heptachlor epoxide		$C_{10} H_5 Cl_7$	0.03 µg/l
Hexachlorobenzene (HCB)		$C_{10} H_5 Cl_7 O$	1 µg/l
Isoproturon		$C_{12} H_{18} N_2 O$	9 µg/l
Lindane		$C_6 H_6 Cl_6$	2 µg/l
MCPA		$C_9 H_9 Cl O_3$	2 µg/l
Methoxychlor		$(C_6H_4OCH_3)_2CHCCl_3$	20 µg/l
Metolachlor		$C_{15} H_{22} Cl N O_2$	10 µg/l
Molinate		$C_9 H_{17} N O S$	6 µg/l
Pendimethalin		$C_{13} H_{19} O_4 N_3$	20 µg/l
Pentachlorophenol (PCP)		$C_6 H Cl_5 O$	9 µg/l
Permethrin		$C_{21} H_{20} Cl_2 O_3$	20 µg/l
Propanil		$C_9 H_9 Cl_2 N O$	20 µg/l
Pyridate		$C_{19}H_{23}ClN_2O_2S$	100 µg/l
Simazine		$C_7 H_{12} Cl N_5$	2 µg/l
Trifluralin		$C_{13} H_{16} F_3 N_3 O_4$	20 µg/l
Chlorophenoxy herbicides (excluding 2,4-D and MCPA)		$C_{10} H_{10} Cl_2 O_3$	90 µg/l
	Dichlorprop	$C_9 H_8 Cl_2 0_3$	100 µg/l
	Fenoprop	$C_9H_7Cl_3O_3$	9 µg/l
	MCPB	$C_{11} H_{13} Cl O_3$	No guideline
	Mecoprop	$C_{10}H_{11}ClO_3$	10 µg/l
		$C_8 H_5 Cl_3 O_3$	9 µg/l

Disinfectants and disinfectant by-products

Appendix D) Drinking Water Standards (WHO)

Group	**Substance**		**Formula**	**Health based guideline by the WHO**
Disinfectants	Chloramines		$NH_nCl^{(3-n)}$, where n = 0, 1 or 2	3 mg/l
	Chlorine		Cl_2	5 mg/l
	Chlorine dioxide		ClO_2	No guideline
	Iodine		I_2	No guideline
Disinfectant by-products	Bromate		$Br\ O_3^-$	25 µg/l
	Chlorate		$Cl\ O_3^-$	No guideline
	Chlorite		$Cl\ O_2^-$	200 µg/l
	Chlorophenols	2-Chlorophenol (2-CP)	$C_6\ H_5\ Cl\ O$	No guideline
		2,4-Dichlorophenol (2,4-DCP)	$C_6\ H_4\ Cl_2\ O$	No guideline
		2,4,6-Trichlorophenol (2,4,6-TCP)	$C_6\ H_3\ Cl_3\ O$	200 µg/l
	Formaldehyde		HCHO	900 µg/l
	MX (3-Chloro-4-dichloromethyl-5-hydroxy-2(5H)-furanone)		$C_5\ H_3\ Cl_3\ O_3$	No guideline
	Trihalomethanes	Bromoform	$C\ H\ Br_3$	100 µg/l
		Dibromochloromethane	$CH\ Br_2\ Cl$	100 µg/l
		Bromodichloromethane	$CH\ Br\ Cl_2$	60 µg/l
		Chloroform	$CH\ Cl_3$	200 µg/l
	Chlorinated acetic acids	Monochloroacetic acid	$C_2\ H_3\ Cl\ O_2$	No guideline
		Dichloroacetic acid	$C_2\ H_2\ Cl_2\ O_2$	50 µg/l
		Trichloroacetic acid	$C_2\ H\ Cl_3\ O_2$	100 µg/l
	Chloral hydrate (trichloroacetaldehyde)		$C\ Cl_3\ CH(OH)_2$	10 µg/l
	Chloroacetones		$C_3\ H_5\ O\ Cl$	No guideline
	Halogenated acetonitriles	Dichloroacetonitrile	$C_2\ H\ Cl_2\ N$	90 µg/l
		Dibromoacetonitrile	$C_2\ H\ Br_2\ N$	100 µg/l
		Bromochloroacetonitrile	$CH\ Cl_2\ CN$	No guideline
		Trichloroacetonitrile	$C_2\ Cl_3\ N$	1 µg/l
	Cyanogen chloride		Cl CN	70 µg/l
	Chloropicrin		$C\ Cl_3\ NO_2$	No guideline

Appendix E) COSTS, SPREADSHEET



Input parameters			
Parameter	Value	Unit	Comment
	50	nm	Distance to add to roundtrip due to deviation from oil unloading port to FW loading terminal
	0	nm	Distance to add to roundtrip due to deviation from oil loading port to FW unloading terminal
	12070	$	Ship operating costs, per day
	55776	$/day	Applicable worldscale freight rate
	-	$/hr	Port costs
	70		fuel consumption tons/day
	450	$/ton	HFO price
	5 %	%	Interest rate
		years	Years until residual value of equipment is 10%
	6800	nm	Distance between oil loading and oil unloading port
		$/ton	FOB cost of water
	20000	m^3/hr	Pump capacity/water loading rate
	20000	m^3/hr	Pump capacity/water unloading rate
	2	hr	Extra time spent manouvering when loading/unloading water, per port
Vs	16	kn	Design sailing speed
Vb	17	kn	Design ballast speed (often Vs+1)
	30	%	Standard ballast load, minimum safe amount, %DWT
	30	%	Water load, in per cent of DWT
	300000	DWT	Deadweight of vessel
	15	years	Lifetime of project
	0	-	Number of roundtrips per year
Ship input parameters			
	43	-	Number of vessels
	20000	ton/hr	Oil loading capacity
	20000	ton/hr	Oil unloading capacity
	6	hr	Time spent manouvering/bunkering etc per port
	336	hr	Offhire per year per vessel

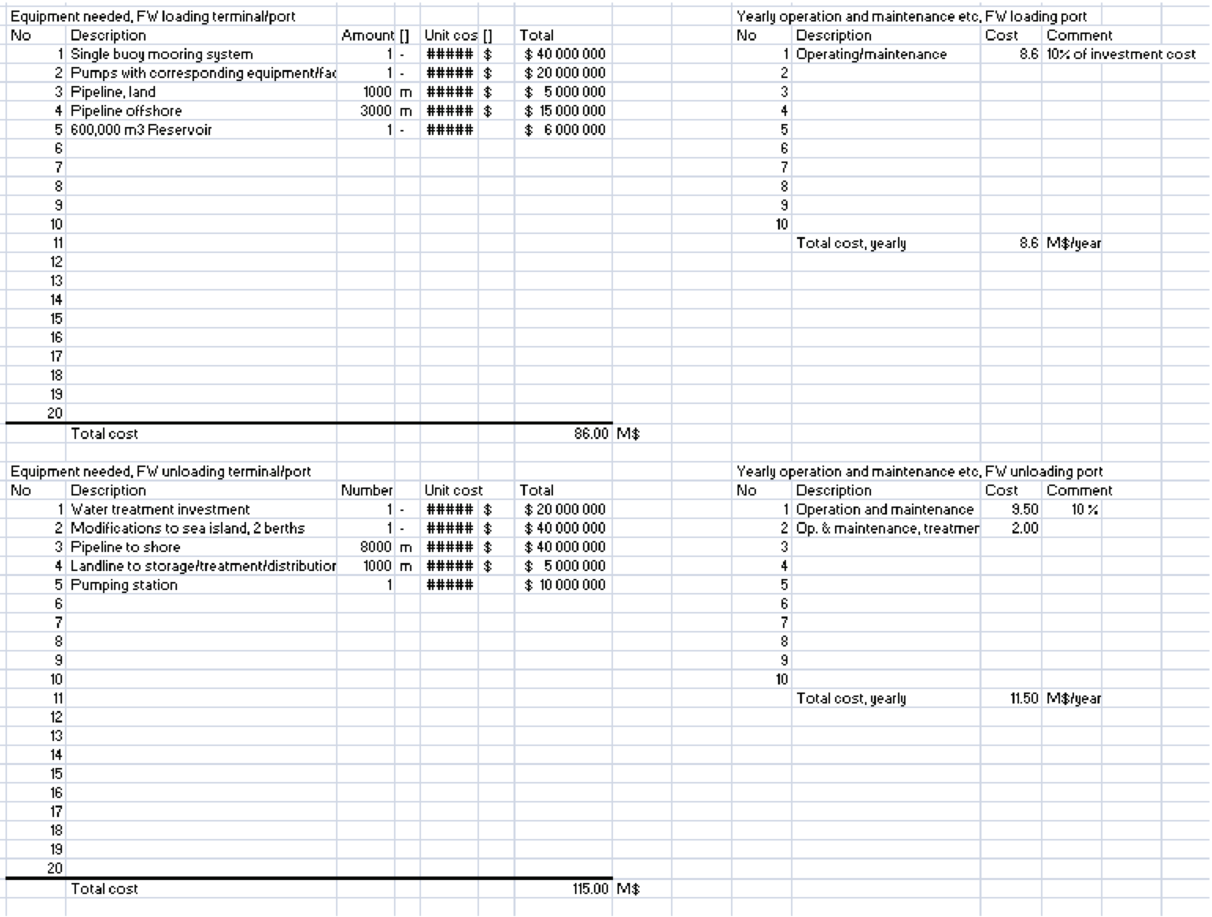
Derived/dependent parameters			
Parameter	Value	Unit	Comment
t,dev,loading	5.1	hrs	Distance to deviate when loading freshwater, ie total distance to add to the roundtrip
t,dev,unloading	2.0	hrs	Distance to deviate when unloading freshwater
t,FWloading	4.5	hrs	Time spent at FW terminal loading FW
t,FWunloading	4.5	hrs	Time spent at FW terminal unloading FW
t,DBC	0.0	hrs	Extra time spent on journey due to deviation from design ballast condition
	10.4		Present value factor
	425.0	hrs	Time spent, fully laden with oil
	400.0	hrs	Time spent, design ballast condition
	400.0	hrs	Time spent, ballast condition with FW cargo/ballast
	90000	ton	Water carried per trip

Operational Profile	Per RT	per year		Grouped			
Port, loading oil	15.0	142.4	2 %	Port, oil	42.0	398.8	5 %
Port, unloading oil	15.0	142.4	2 %	FW relate	20.1	191.1	2 %
Port, other (oil)	12.0	114.0	1 %	Sailing, lo	425.0	4035.7	46 %
Port, loading FW	4.5	42.7	0 %	Sailing, b	400.0	3798.3	43 %
Port, unloading FW	4.5	42.7	0 %	OH		336	4 %
Port, other (FW)	4.0	38.0	0 %			8760.0	
Sailing, loaded	425.0	4035.7	46 %				
Sailing, ballast/FW	400.0	3798.3	43 %				
Sailing, deviating to load FW	5.1	48.7	1 %				
Sailing, deviating to unload FW	2.0	19.0	0 %				
Offhire		336	4 %				
Total	887.1	8760.0					

Yearly roundtrips	9.5	
Amount of oil carried per year	2.8488	mill ton
Amount of FW carried per yer	0.8546	mill ton
No of ships		
Total fw carried per year	36.749	mill ton

Costs		
Transport costs	OPEX	Freight rate
One ship one leg	$ 17 461	$ 37 475
one yr cost, all ship	$ 7 129 736	########
Cost US$/m3	$ 0.19	$ 0.42

Appendix E) /Costs, Spreadsheet



Equipment needed, FW loading terminal/port

No	Description	Amount	[]	Unit cos	[]	Total	
1	Single buoy mooring system	1	-	#####	$	$ 40 000 000	
2	Pumps with corresponding equipment/fac	1	-	#####	$	$ 20 000 000	
3	Pipeline, land	1000	m	#####	$	$ 5 000 000	
4	Pipeline offshore	3000	m	#####	$	$ 15 000 000	
5	600,000 m3 Reservoir	1	-	#####		$ 6 000 000	
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
	Total cost					86.00	M$

Yearly operation and maintenance etc, FW loading port

No	Description	Cost	Comment
1	Operating/maintenance	8.6	10% of investment cost
2			
3			
4			
5			
6			
7			
8			
9			
10			
	Total cost, yearly	8.6	M$/year

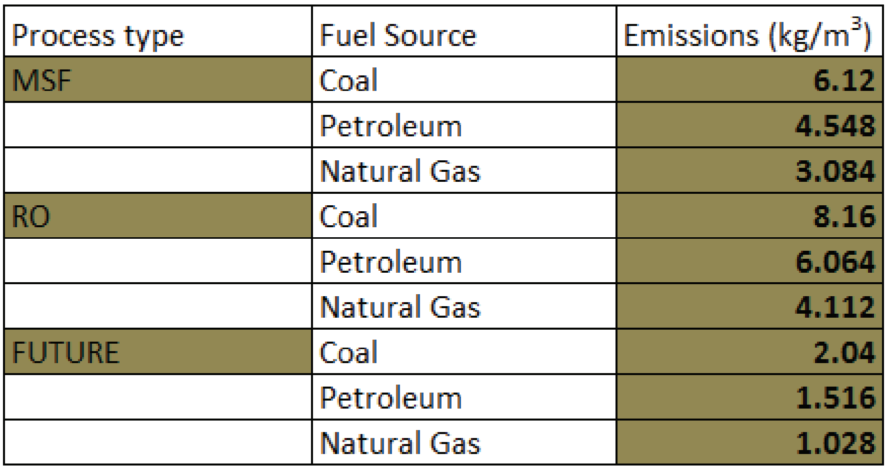
Equipment needed, FW unloading terminal/port

No	Description	Number		Unit cost		Total	
1	Water treatment investment	1	-	#####	$	$ 20 000 000	
2	Modifications to sea island, 2 berths	1	-	#####	$	$ 40 000 000	
3	Pipeline to shore	8000	m	#####	$	$ 40 000 000	
4	Landline to storage/treatment/distributior	1000	m	#####	$	$ 5 000 000	
5	Pumping station	1		#####		$ 10 000 000	
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
	Total cost					115.00	M$

Yearly operation and maintenance etc, FW unloading port

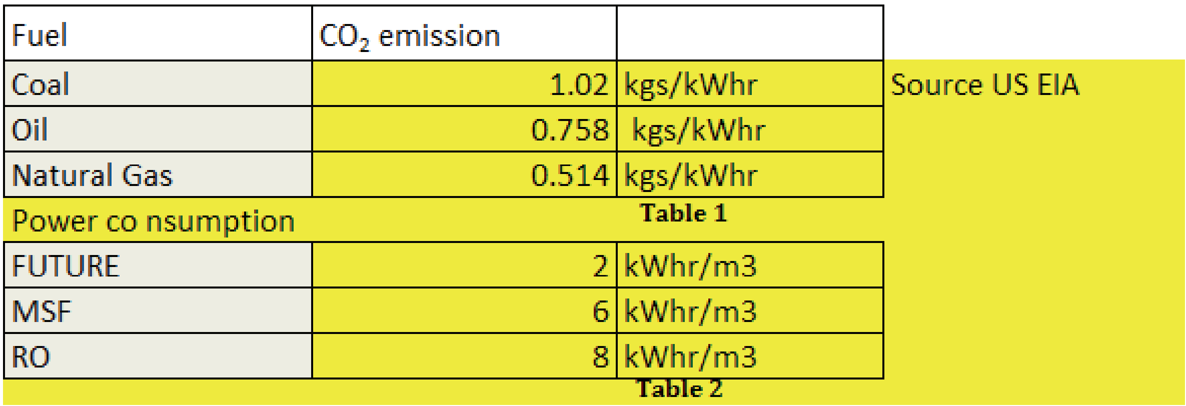
No	Description	Cost	Comment
1	Operation and maintenance	9.50	10 %
2	Op. & maintenance, treatmer	2.00	
3			
4			
5			
6			
7			
8			
9			
10			
	Total cost, yearly	11.50	M$/year

Appendix F) ENVIRONMENTAL CALCULATIONS



Process type	Fuel Source	Emissions (kg/m^3)
MSF	Coal	**6.12**
	Petroleum	**4.548**
	Natural Gas	**3.084**
RO	Coal	**8.16**
	Petroleum	**6.064**
	Natural Gas	**4.112**
FUTURE	Coal	**2.04**
	Petroleum	**1.516**
	Natural Gas	**1.028**

Emissions=Table(1) *Table(2)



Fuel	CO_2 emission		
Coal	1.02	kgs/kWhr	Source US EIA
Oil	0.758	kgs/kWhr	
Natural Gas	0.514	kgs/kWhr	
Power co nsumption		**Table 1**	
FUTURE	2	kWhr/m3	
MSF	6	kWhr/m3	
RO	8	kWhr/m3	
		Table 2	

Appendix F) Environmental Calculations

Power Required			Fuel consumption	Transportation Emissions calculation							(12)Emissions from onshore pumping(SBT FWBH)CO2(Tons)^4 (0.26 * (7)/1000)	(13)Emissions from onshore pumping(Cargo space FWBH)CO2(Tons)4 (0.26 * (1)/1000)	(14)Total CO_2 tons(SBT FWBH)((12)+(9))	(15) Total CO_2 tons(Cargo space FWBH)(11)+(13)	(16)Emissions SBT FWBH kg-CO_2/m^3((14)/(7))
(1)DWT	(2)Speed	(3)BHP$^{(1)}$	(4)(Ton/day)$^{(2)}$	(5)Emission/day$^{(3)}$(3.19*(4))	(6)Deviation(days)	(7)SBT volume(m3)	(8) SBT FWBH emissions(CO_2 - kgs/m^3)((5)*(6)*1000/(7))	(9)Total SBT FWBH emissions CO_2(Tons)((8)*(7)/1000)	(10)Cargo spaces FWBH emissions(CO_2 - kgs/m^3)((5)*(6)*1000/(1))	(11) Total emissions from Cargo Space FWBH(tons)((10)*(1)/1000)					
100000	14	17261.5	52	166.5	0	25000	0	0	0.1	6.5	7	26	7	33	0.3
	14		52	166.5	1	25000	6.7	167	1.7	173.0	7	26	173	199	6.9
	14		52	166.5	3	25000	20.0	500	5.1	506.0	7	26	506	532	20.2
100000	15	18076.1	55	174.4	0	25000	0.0	0	0.1	6.5	7	26	7	33	0.3
	15		55	174.4	1	25000	7.0	174	1.8	180.9	7	26	181	207	7.2
	15		55	174.4	3	25000	20.9	523	5.3	529.6	7	26	530	556	21.2
100000	16	19006.9	57	183.4	0	25000	0.0	0	0.1	6.5	7	26	7	33	0.3
	16		57	183.4	1	25000	7.3	183	1.9	189.9	7	26	190	216	7.6
	16		57	183.4	3	25000	22.0	550	5.6	556.6	7	26	557	583	22.3
200000	14	25233.1	76	243.4	0	50000	0.0	0	0.1	13.0	13	52	13	65	0.3
	14		76	243.4	1	50000	9.7	243	1.3	256.4	13	52	256	308	5.1
	14		76	243.4	3	50000	29.2	730	3.7	743.2	13	52	743	795	14.9
200000	15	26047.7	79	251.3	0	50000	0.0	0	0.1	13.0	13	52	13	65	0.3
	15		79	251.3	1	50000	10.1	251	1.3	264.3	13	52	264	316	5.3
	15		79	251.3	3	50000	30.2	754	3.8	766.8	13	52	767	819	15.3
200000	16	26978.5	82	260.2	0	50000	0.0	0	0.1	13.0	13	52	13	65	0.3
	16		82	260.2	1	50000	10.4	260	1.4	273.2	13	52	273	325	5.5
	16		82	260.2	3	50000	31.2	781	4.0	793.7	13	52	794	846	15.9
300000	14	31920.4	97	307.9	0	75000	0.0	0	0.1	19.5	20	78	20	98	0.3
	14		97	307.9	1	75000	12.3	308	1.1	327.4	20	78	327	405	4.4
	14		97	307.9	3	75000	37.0	924	3.1	943.3	20	78	943	1021	12.6
300000	15	32735.0	99	315.8	0	75000	0.0	0	0.1	19.5	20	78	20	98	0.3
	15		99	315.8	1	75000	12.6	316	1.1	335.3	20	78	335	413	4.5
	15		99	315.8	3	75000	37.9	947	3.2	966.8	20	78	967	1045	12.9
300000	16	33665.8	102	324.8	0	75000	0.0	0	0.1	19.5	20	78	20	98	0.3
	16		102	324.8	1	75000	13.0	325	1.1	344.3	20	78	344	422	4.6
	16		102	324.8	3	75000	39.0	974	3.3	993.8	20	78	994	1072	13.3
500000	14	43377.1	131	418.4	0	125000	0.0	0	0.1	54.2	33	130	33	184	0.3

Power Output

(1) BHP= $156.6 + 6.271\ DWT^{0.667} + 1.291\ SPEED^3$

Fuel Consumption

(2) t/day= Specific fuel consumption*BHP*24

(2.1) SFC = 0.000126 t/BHP/hour (WARTSILA)

Emission factors [ton Emmissions/ton fuel]

	HFO
(3) CO2	3.19

Pumping CO2 factor

(4) 0.26 kg/m^3 Kimberley report