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While the current methods used to obtain, store, and distribute fresh water for consumption and hygiene currently employed by the military are effective under present conditions, future threats and requirements for distributed operations will necessitate a better expeditionary system. It must be one that is capable of suppling water without over-burdening the local populace and without relying on increasingly vulnerable supply hubs and depots. As resources become more scarce and as operations across the ROMO increase, the DOD must seek a more effective means to supply the troops. Identifying a comprehensive set of resupply options, together with adopting new technology, will provide uninterrupted logistics.

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MASTER OF MILITARY STUDIES

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SUBMITTED IN PARTIAL FULFILLMENT
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MASTER OF MILITARY STUDIES

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AY 2016-2017

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Executive Summary

Title: Our Tail Has a Tail: Using Hybrid Logistics to Adapt to Water Scarce Environments with Minimum Impact to Military Operations from 2025 and Beyond

Author: Major Veronica L. Kaltrider, USMC

Thesis: While the current methods used to obtain, store, and distribute fresh water for consumption and hygiene currently employed by the military are effective under present conditions, future threats and requirements for distributed operations will necessitate a better expeditionary system. It must be one that is capable of suppling water to service members without over-burdening the local populace and without relying on increasingly vulnerable supply hubs and depots. As resources become more scarce and as operations across the ROMO increase, the DOD must seek a more effective means to supply the troops. Identifying a comprehensive set of resupply options, together with adopting new technology, will provide uninterrupted logistics to forward deployed maneuver elements, and enable aggregated or disaggregated operations that are less reliant on fixed infrastructure.

Discussion:

The FOE is described as a complex, multi-domain environment where state, non-state, and transnational threats will proliferate and intensify. The environmental drivers of instability, which include population growth, economic competition, and social orientation, will create an atmosphere where additional drivers and forecasts of the FOE from DOD wide and service capstone concepts will be realized.

Population growth spurts or the effects of global warming can cause water insecurity, affecting the global economy and social systems. As these situations worsen, new technology to overcome the challenges will further exacerbate tensions within affected regions. These tensions will give rise to proliferation of weapons of mass destruction and nuclear arms as protection measures.

The disorder and instability will require United States intervention, but A2/AD threats, will preclude access to infrastructure ashore. Therefore, DOD must have an agile force that is capable of rapid deployment and redeployment into a theater of operations. It must also have the ability to provide logistics support over longer distances without massive buildup of logistics ashore.

A critical requirement for operations is water. In regions of current or impending water scarcity, is the DOD must not worsen the situation upon entry in the theater of operations. Therefore, the current systems used to provide potable water for service members may become ineffective if the conditions suggested in the services' capstone concepts develop. Specifically, each system requires an existing body of water which may not be available. However, if the services adopt the recommended logistics conceptual framework, leaders could use each consideration to gain an advantage over the adversary.

Conclusion: The bottom line is, if DOD uses new technology and hybrid logistics to support requirements, i.e. parts, ammunition, and water, using the conceptual framework; this will allow troops to operate in the FOE and will greatly reduce the logistics tail.

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Finally, I must express my profound gratitude to my parents, my mother- and father-in-law, and my husband for their unfailing love and encouragement throughout this process.

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Introduction

All the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again.

-- Ecclesiastes 1:7

The world is overflowing with water – there is no beginning or end. It is the largest geographic feature on earth's surface that changes in a continuous hydrologic cycle and it exists in three states: solids – glaciers; gases – vapor; and liquids – oceans, rivers and aquifers; et cetera.[1] Water also exists in every plant and animal, and though some may not need hydration for years, all require water to survive.[2] In fact, the human body, which is made up of over 60 percent water, can survive many days without water depending on the conditions and physical exertion[3]. But ultimately, without proper water balance, chemical and biological processes become interrupted and unable to function and sustain life.

There is no question regarding the existence or importance of water; but not all available water is actually usable. How might lack of water affect military operations, and how can the US military and its allies and partners turn such a liability into a potential advantage? From this standpoint, this paper seeks to answer the following questions:

1. Why might current systems used to provide potable water not adequately support the Range of Military Operations in the future operating environment (FOE), 2025 and beyond?
2. How can the Department of Defense (DOD) leverage water scarcity to gain the strategic, operational, or tactical advantage against an adversary in the FOE?
3. How can the DOD use technology to provide commanders with options to increase maneuverability, support distributed operations for extended periods, and eliminate a

constant need for regular resupply of water, without negatively impacting the environment (ecosystem) or local population?

4. Water being heavy, is there an innovative solution to "lighten the load" for individual and larger elements?

The essential thesis of the following analysis is that, while the current methods used to obtain, store, and distribute fresh water for consumption and hygiene currently employed by the military are effective under present conditions, future threats and requirements for distributed operations will necessitate a better expeditionary system. It must be one that is capable of suppling water to service members without over-burdening the local populace and without relying on increasingly vulnerable supply hubs and depots. As resources become more scarce and as operations across the ROMO increase, the DOD must seek a more effective means to supplyt the troops. Identifying a comprehensive set of resupply options, together with adopting new technology, will provide uninterrupted logistics to forward deployed maneuver elements, and enable aggregated or disaggregated operations that are less reliant on fixed infrastructure.

There may be many uses for the concept discussed below; nonetheless, the purpose of this paper is to discuss possible military application (specifically Army and Marine Corps) of new technology in order to gain the strategic, operational, or tactical advantage across the ROMO. This paper addresses ways to provide sustainable, potable water for consumption or hygiene to maneuver forces in the FOE. To illustrate the importance of water, this paper examines current scientific concerns with water supply and historical cases where water had an enormous impact on military operations. While offering a broad comparative analysis of techniques used to supply war, the discussion below will show how adopting specific new technology in water resupply could give DOD significant advantages and possible cost savings.

Chapter 1: Defining the Military Problem

Water poses a military problem for US, allied, and partner nation forces in two basic respects. On the one hand, it is a key element of operational logistics; and on the other hand, it is a key driver in the operating environment. In logistical terms, the basic problem comes down to this: during military operations, warfighters require a substantial amount of water to remain hydrated. More specifically, Dr. Scott Montain states, "an individual soldier's daily water requirements to sustain hydration can range from 2L/d to an excess of 12 L/d, depending on weather conditions, workload, and physical size."[4] Although 2 L/d is easily achieved both in garrison and during deployment, 12 L/d will require concerted effort and coordination by military logistics support personnel and field commanders to ensure that adequate fluid is available."[5]

The second reason "why water" is because introduction of United States forces into foreign territory, whether in a permissive, uncertain, or hostile environment, may unintentionally exacerbate preexisting water stress conditions and create more disorder and tension. As anticipated in current DOD planning documents, the future operating environment poses both numerous resource challenges to future world populations, water foremost among them, and significant logistical challenges for US, allied, and partner nation military forces. These challenges merit close attention.

On the one hand, according to the Capstone Concept for Joint Operations (CCJO), Marine Corps Operating Concept (MOC), Expeditionary Advance Base Operations (EABO), and Global Trends 2025, among other DOD and non-DOD resources, the FOE will experience an influx of personnel residing and working in the littorals. There will be fewer host nations and available locations where the military can establish lodgments in order to conduct sustainment operations, unless the United States decides to accept significantly greater levels of destruction to civilian lives and property (simply to insert troops and move inland) than we have generally recognized as tolerable in the achievement of military ends in any operation since the Second World War (WWII). These logistical challenges may negatively impact maneuver force operations.

Moreover, during military operations, DOD logistical requirements place demands on the limited supplies of natural resources, including safe drinking water, throughout all phases across the range of military operations (ROMO). This is because they deploy large numbers of personnel and equipment into the area of operations (AO) and, in support for those forces, often create a logistical network that relies on existing land-space, infrastructure, and fresh water sources (used to purify and store for hygiene and consumption). Alternatively, the DOD can contract many of its requirements, water included, when expeditionary assets are not usable.

On the other hand, the expected increase in long-range, precision-guided munitions (PGM) in anti-access/area denial (A2/AD) systems will impact the way that the military currently conducts operations. The "iron mountain" (massive build-up of supplies ashore) is no longer feasible, as it provides too easy and too valuable a target. Additionally, the proliferation of A2/AD technologies, including unmanned aerial systems (UAS) swarms as well as PGMs, can make traditional delivery of supplies from maritime vessels or air transport unsupportable. Even a standoff hub over the horizon, out of reach from enemy systems, would still need connectors to reach the shore, and traditional connectors by both air and sea would remain relatively slow and vulnerable. Forces must therefore have the ability to maneuver without the availability of a logistics hub to provide sustainment. As we will see, moreover, the challenge facing the US in the 21st century is far from new in the annals of human warfare.

Chapter 2: Historical Water Strategies and Tactics

The result was disastrous: the blazing heat and the lack of water caused innumerable casualties, especially among the animals, most of which died of thirst or from the effects of the deep burning sand…Not the least hardship was the varying length of the marches, as the fact that they never knew when they would find water made regular, normal marches impossible.

-Arrian of Nicomedia (Lucius Flavius Arrianus), Anabasis

The issue of water scarcity is not new. It is documented, albeit embedded in the history of military operations, and therefore most often it is overlooked even though most non-battle injuries or deaths occurred as a result of water shortages or contaminated water supplies. Nevertheless, there are multiple examples where logistics requirements directed the execution of a plan or the lack of water resources caused a military to fail in accomplishing their mission.

Alexander the Great is a prime example of incorporating logistics and provisioning of the army into the warfighting plan at the strategic and tactical levels[6]. As part of his campaign plans, he used local resources and he also imported food and water for his troops.[7] To ensure speed and maneuverability, Alexander continued a practice[i] to limit wagons: he restricted families and servants from troop movements, and he required troops to carry their own personal belonging to reduce logistics requirements.[8] During forced marches, each individual received two quarts of water and animals received eight gallons, per day, resupplied according to the distance.

Prior to his six day east to westward march through the Gedrosian desert[ii], Alexander the Great found most of his plans null and void.[9] Weather held his fleet, stocked with supplies, until

[i] David Engels suggests that Alexander the Great continued the logistics and organizational changes established by Philip, who trained his men to carry their full panoply and provisions to reduce the number of servants, forbade carts so as to reduce the number of animals, and prohibited women from accompanying the army.
[ii] According to the Encyclopedia Iranica, Gedrosia (or Kedrosia) is located in south Pakistan and southeast Persia. "province extended from the land of the Oritans, along the western banks of the Arabius or Arabis River (the modern Hab, west of Karachi) and the nearby mountains (Kirthar range; the Arbita mountains of Ptolemy, Geography 6.21) to the borders of Carmania (Arrian, Anabasis Alexandri 6.22-26)."

September but because the area he occupied had been ravished by his army, he had to continue his movement.[10] The climate, along with the lack of water, caused numerous fatalities; many suffered from exhaustion, thirst, and sunstroke.[iii] When the army found water after a hot march, they gorged themselves and suffered from hyponatremia.[iv]

The planning of Alexander the Great demonstrates how leaders can miscalculate logistics. Writer Donald Engels asserts that analysts could trace the conquests of Alexander the Great because all of the relevant information – "climate, human and physical geography, available methods of transport, and the agricultural calendar of a region," – is "known."[11] His statement suggests that Alexander the Great incorporated estimates of supportability in each of his strategic plans. Unfortunately, despite all of his planning, Alexander the Great lost roughly three quarters of his Macedonian Army when its water supply ran out while they traversed the Gedrosian desert.[12]

After the Ottoman Empire allied with Germany during the First World War (WW I), allies and the Australian and New Zealand Army Corps (ANZAC) conducted an offensive on the Gallipoli Peninsula.[13] Fighting stalled and both the Ottoman Empire and Allied forces found themselves in poor conditions as they confronted horrible sanitary conditions and lack of food and water. Fighting began in late April, 1915, and during this time, temperatures are rather moderate but as the season progresses to summer, the temperatures soar into triple digits; and for the eight months of occupation, the weather conditions would change considerably.[14] Ultimately, allied forces lost the war that officially closed in January 1916 as a result of poor conditions. Examining the conditions at Gallipoli, it is easy to see why the allies suffered great

[iii] Alexander in the Gedrosian Desert: http://www.livius.org/sources/content/arrian/anabasis/alexander-in-the-gedrosian-desert/
[iv] Alexander in the Gedrosian Desert: http://www.livius.org/sources/content/arrian/anabasis/alexander-in-the-gedrosian-desert/

loss. First, the extreme weather, living conditions, and food scarcity, would cause disease and illness throughout the entrenchments. More importantly, there was no natural water source available, save the ocean and perhaps a few springs (see Appendix G for a map of the area).

In the book, *ANZAC,* the editors describe food and water as a way to provide troops the nutrients needed to fight but it also describes the emotional aspect, i.e. as a morale enhancer. Food for the ANZAC troops, such as tins of jelly, biscuits, and meat, lost its favor. In contrast, the Ottoman Army supplied their men cooked rations. The difference between the two is significant; where the ANZACs lost interest because of the taste, swarms of flies, and "odour sickeningly reminiscent of that exhaling from the corpses," which contributed greatly to deteriorating health conditions, the Ottoman army had a heathier environment and diet of fresh fruits, vegetables, and meats of roughly 3,000 calories per day.[15]

For water, the editors stated that the ANZAC had water bottles and steel containers used to boil water. Most often, the ANZAC army made tea because they lacked fresh water and they also used the hot drinks to suppress their appetite. Because of the severe lack of water fresh water sources, "a water condenser had been built on ANZAC Cove, most of the water was transported…then pumped ashore into large storage tanks."[16] The ANZAC also used whatever metal containers they had to transport the heavy loads of water between sites. Again, the Ottoman troops had sufficient wells, fountains and springs to sustain their force.

The inability of the ANZAC to provide food and fresh water to troops impacted the entire mission. Not only do food and water impact people physically, it also affects their psychological ability to withstand the pressures of war. In this example, it shows the ingenuity of the ANZAC to provide water to their troops but the lack of transport mechanisms to get the water to the front lines posed a significant logistical challenge. This example also demonstrates a tactic that the

DOD often employs when it enters a theater of operations – establishing a supply hub and distribution network. However, as multiple 21st century FOEs suggest, the option to maintain a logistics footprint ashore will be limited due to crowded urban littorals and lethal A2/AD systems. Most fundamentally, the world of the 21st century will be struggling to supply itself with sufficient water. To understand the full dimension of the water problem in the future operating environment, we must understand water scarcity itself.

Chapter 3: Understanding Water Scarcity

When the well is dry, we learn the worth of water.

--Benjamin Franklin, Poor Richard's Almanac

There are multiple uses for water. Domestically, people use water for consumption and hygiene but most domestic water expenditure is in agriculture. There are also commercial and industrial uses for water such as industrial processing or the maintenance of navigable channels in various waterways.

Regrettably, the world is on the verge of a water crisis. Not only is useable water endangered, but water scarcity often goes unnoticed and therefore it does not receive the level of attention or support required to stabilize an affected area. The 1972 United States' Congressional staff survey of current research on water resources stated that parts of Europe and the United States took water for granted because water usually came to the area naturally, through precipitation that provided enough quality water to support agricultural and domestic requirements.[17] Countries in arid, desert regions do not have the benefit of such vast precipitation and usually suffer with some form of water insecurity.[18] To that end, external aid from multilateral agencies in "first world"[v] countries is critical to meeting the needs of developing nations, but the aid only meets 6 percent of the estimated need.[19] Currently, reports from the UN and other environmental organizations have increased awareness of the 780 million people who do not have access to clean drinking water, and of the statistics regarding patients suffering from diseases associated with lack of access to safe water, inadequate sanitation and

[v] According to One World Nations Online, the world was divided into separate blocs after World War II. The first world countries are American influenced, democratic-Industrial commonly described as developed; the second world countries are communist-social states aligned with Russia; the third world are non-aligned developing states such as Africa, parts of Asia, and Latin America; and the fourth world are comprised of indigenous people "living within or across national state boundaries."

poor hygiene.[20] The UN has also sounded the alarm regarding what they believe to be the five drivers, or pressures, on water: demographic, economic, and social drivers; technological innovation; policies, laws, and finance; and climate change and possible futures.[21]

Changes in natural landscape associated with regional demographics, global economy, and social dynamics present major threats to sustainability of water resources.[22] As populations grow (mostly in water stressed developing countries), migrate, age, and urbanize, increased demands from consumption and pollution from informal settlements will decrease the availability and quality of water, creating an environment where people become more vulnerable.[vi] The global community and international trade also contribute to water stress. As indicated "trade in goods and services can aggravate water stress in some countries while relieving it in others through flows of 'virtual water', particularly in the form of imported agricultural commodities."[23] Equally, social dynamics often influence individual attitudes concerning the environment. For instance, impoverished areas usually contribute to water pollution because of poor hygiene practices. Impoverished areas also have higher levels of uneducated people, resulting in a lack of understanding concerning the importance of the environment or the local ecosystem.[24]

The above-mentioned drivers will also have an impact on technological innovation which can have both positive and negative effects on the environment. The key message authors Richard Connor and Walter Rast wish to convey is that "technology is constantly evolving, and the availability of technologies can differ widely between developed and developing countries because of impediments to dissemination of research and adaptation to local conditions."[25] The

[vi] The World Health Organization definition of an informal settlement, adopted from the UN Habitat Programme, states that 1) structures are built and/or people occupy property illegally; and 2) unplanned, uncoordinated housing incompliant with regulations.

challenge with technology is ensuring that it is mutually beneficial to both developed and developing countries and to balance people against the environment. That is to say, as technological advances increase life expectancy, technology must also increase ways to sustain the growth with limited degradation to the natural environment, all the while ensuring that the "haves and have-nots" both benefit. Otherwise, technology simply feeds back into the recursive loop of demographic, economic, and social drivers of water scarcity.

Policies and laws concerning water resources are complex and can be confusing because they are multilayered – involving local, regional, national, international organizations, and state/non-state actors, depending on where the water (surface, ground, coastal, or international water) is located and how closely it is tied to global economics and the other drivers. Although not completely binding or enforceable, many countries have committed to water sharing agreements, designed to avoid conflict where transboundary waters are concerned. However, as Gunilla Björklund, Et al., state, "effective implementation and enforcement require adequate institutional and governance framework – one that is legitimate, transparent, and participatory and that has proper safeguards against corruption," which is difficult to manage in developing nations or failing states. Moreover, developed countries or countries "upstream" can use water resources to challenge the sovereignty and influence water demand of another state, contributing to regional instability.

The environmental influences such as the potential impact of climate change are uncertain, but should an extreme climatic event occur, it is expected that natural resource availability will decline. To summarize, rivers, flora and fauna, energy production, crops, navigation, and the like can change if climate change affects the hydrologic cycle.[26]

Any severe change can negatively affect the global economy and international policies. In fact, in addition to observing a potential disaggregation of the European Union and increase of private corporations in the political decision making process, the United Kingdom's Foreign & Commonwealth Office of Risk Assessment made the following conclusions and observations during a climate change planning scenario:[27]

1) Climate change may trigger increased nationalism and policies of internalization in developed countries.

2) Large scale, climate-induced migration and displacement may impact a country's international policies, economic situation, and defining cultural attributes.

3) Competition for limited resources may increase as a source of friction and shape policies and international relations.

4) The consensus and control of climate-related technologies may result in an emerging disparity between regions, as not all countries view these technologies in the same way, and there is little framework for their use or management.

Other environmental impacts can be initiated by human activity. According to book Gulbenkian Think Tank on Water, “deforestation, veld fires, and inappropriate farming and animal husbandry practices can lead to degradation and desertification of watersheds and catchment areas, and reduce the amount of usable safe and clean water available downstream.”[28] Already, there are visible signs of such activity. Deforestation, as in the Amazon rain forests, or wild fires in California, are well known examples of humans interfering with the environment. Whether intentional or not, these activities will negatively impact water availability.

While some might describe the world as utopia, others might have a grimmer perspective on the current state. Regardless, as populations grow into mega cities, water borne diseases, new demand from industry, policies and diversion of water for economic gain, drought and the effects of global warming increases, availability of fresh water will inevitably become scarce contributing to state failure and creating conditions whereby non-state actors thrive increasing the potential for conflict. With this overview in mind, we can now consider the future operating environment for military forces, with a particular emphasis on water.

Chapter 4: The Future Operating Environment

Although conflict, violence, and war endure, the methods through which political goals are pursued are always evolving…The Joint Force will best contribute to a peaceful and stable world by developing capabilities and operational approaches attuned to the evolving character of conflict.

-Vice Admiral Kevin D. Scott, Joint Operating Environment 2035

Since WWII, when the United States emerged as a "superpower," it has been regularly involved in international relations as a quasi-enforcer of world peace. However, the United States cannot control the global landscape. The international community is in a perpetual state of change, fluctuating in and out of conflict as alliances and partners change, new countries rise to power, economies develop, populations grow, and resources deplete, creating an unstable global situation. One day, there is relative peace, the next all-out-war – in any world where people live, conflict exists.

To understand the complexities of the global environment, DOD service components created capstone conceptual guides to articulate their vision, prepare their service members to operate in an increasingly challenging world, and provide detailed guidance, as necessary, in order to accomplish their national security objectives. Each of the capstone concepts demands flexible, dynamic organizations that can operate in a complex, multi-domain environment.

As capabilities evolve, so do adversaries. There are many ways to describe future threats, whether state/non-state actors, transnational political/criminal organizations, near-peer competitors, or others. Regardless of who threatens the United States national interests, the DOD will contend with an adaptive adversary in an increasingly complex environment.

To address these threats, the Capstone Concept for Joint Operations (CCJO) and the Joint Operating Environment (JOE) place a significant emphasis on technology proliferation in context of its potential origins. Specifically, the CCJO makes note of four "mature and emerging challenges,": catastrophic, proliferation of weapons of mass destruction; irregular, state or non-state actors using unconventional techniques to counter a more powerful adversary; disruptive, use of new technology to subvert US advantages and disrupt military operations; and traditional, conflict with state actors.[29] The JOE 2035 continues by stating that the conditions of the future security environment will allow persistent disorder potentially amplified by proliferation and exploitation of technology in order to withstand the United States technological overmatch.[30]

In addition to the aforementioned threats, the JOE recognizes the impact of "human geography" as summarized in the five subcategories below:

1. Intensifying consequences of population growth and migration – asymmetric population growth patterns, mass migration and irreconcilable immigrants, mass migration and rejected immigrants or minorities.
2. Urban concerns as global security issues – demand for food or water exceeding local capacity for affordable delivery expansion of under-governed urban spaces, emergence of global cities as international actors.
3. Evolving Ideological Conflict – declining legitimacy of state authority, rapidly shifting group identities, increasing ideological polarization.
4. Alternative Hubs of Authority - organizations filling spaces vacated by states, an accelerating diffusion of power, cooperation/convergence among terrorist and criminal organizations, globalized criminal and terrorist networks
5. The Rise of Privatized Violence – adaptive irregular/sub-state adversaries, disruptive manufacturing technologies and the urban arsenal, weaponization of commercial technologies.[31]

The Army Operating Concept, emphasizes winning despite an unpredictable, complex environment with multiple dilemmas, options, domains and partners through the use of technology to reduce sustainment demands.[32] To address logistics requirements, the Army seeks to provide sustainment support across air, land, and sea domains using "fuel efficient vehicles and systems, improved reliability, locally generated power and water, and other efforts."[33] It further states that they will produce at the point of need perhaps at a strategic sustainment base. Unfortunately, the Army's concept seems somewhat disconnected from the realities it identified. Specifically, if the adversary takes advantage of population growth to avoid US strength and "freedom of movement and action across all domains are increasingly challenged by elusive land-based threats," how and where will the Army provide logistics support; especially if there is limited space or no useable infrastructure to develop an Expeditionary Advance Base (EAB)?[34] That is to say, the Army's conceptual document does not make clear where or how power and water will be supported.

The Marine Corps Operating Concept (MOC) identified five drivers to the future operating environment; complex terrain, technology proliferation, information as a weapon, battle of signatures, and increasingly contested maritime domain.[35] Likewise, the Expeditionary Advanced Base (EAB) Operations Final Report states, "the adversary possesses a robust set of Intelligence, surveillance, and reconnaissance (ISR) capabilities in all domains; these capabilities provide accurate and timely tracking of targets, sufficient for decision-making…it will be difficult for friendly aircraft and naval assets to avoid detection, if not persistent tracking."[36] The EABO further states that the adversary has ballistic missiles capable of engaging naval targets. Each of the drivers in the MOC and the EABO assessment points to significant problems for sea-based operations or lack of available land-based lodgments. The Marine Corps therefore states that it “redesigned our logistics to support distributable forces across a dynamic and fully contested battlespace – because iron mountains of supply and lakes of liquid fuel are liabilities and not supportive of maneuver warfare.”[37] The general principle behind the Marine Corps logistical framework is to reduce the load of individual Marines, to establish and disestablish logistics capability rapidly, and to provide support to a widely-disbursed battlefield.

Analogous to DOD attempts to provide a reasonable assessment of the future operating environment, multiple civilian affiliates and non-DOD organizations like the National Intelligence Council (NIC), United Nations (UN), and National Aeronautics and Space Administration (NASA), also created trend analysis or assessments that have greatly contributed to DOD efforts and the whole of government outlook concerning the FOE, writ large. For example, in Strategic Paradigms 2025, the authors provide an analysis of regional trends, noting the political, economic, and social orientation of each respective county; and more importantly, suggest that the face of war is changing because of drivers in the aforementioned categories. As a result, the authors expect an increase in the use of weapons of mass destruction, nuclear proliferation and directed energy weapons[vii], and emphasis on asymmetrical strategies (i.e. information warfare, psychological operations, offsetting of conventional capabilities, and denial of space operations).[38] Generally speaking, the Geneva Convention and “just war theory” will have little relevance in future wars as state, non-state, or transnational actors conduct “dirty little wars” where anything is permissible.[39] Consequentially, the demand for Special Operations Force capabilities will increase and the use of conventional forces abroad will decrease, due to

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[vii] Jacquelyn Davis and Michael Sweeney state that the directed energy weapon, such as the U.S. Air Force’s Airborne Laser (ABL), will bring about a new era of warfare where laser technology has tactical applications and could strike an enemy’s aircraft. They state that there are implications in both air defense and offense operations and that the directed energy weapon can potentially be used as a space based laser.

the expected increases in population, construction, and urbanization in the littorals described earlier.

Likewise, the NIC makes similar predictions and suggests the following:

> 1. Individual empowerment will accelerate owing to poverty reduction, growth of the global middle class, greater educational attainment, widespread use of new communications and manufacturing technologies, and health-care advances.
> 2. There will not be any hegemonic power. Power will shift to networks and coalitions in a multipolar world.
> 3. The demographic arc of instability will narrow. Economic growth might decline in "aging" countries. Sixty percent of the world's population will live in urbanized areas; migration will increase.
> 4. Demand for food, water, and energy resources will grow substantially owing to an increase in the global population. Tackling problems pertaining to one commodity will be linked to supply and demand for the others.

At the same time, the UN reports a global increase in the population (see population charts in Appendix A) coupled with a steady decline in natural resources.[40] As previously suggested, these changes have significant political and economic implications for geopolitics. The projections and findings of each organization lend themselves to an existing world order already in a steady decline. For war fighters, a holistic view of potential future "realities" can help shape strategy and assist in determining the means and ways to achieve the desired outcomes of conflict.

Against this background, it is possible to understand better the specifically *military* problem of water in the future environment, which we have defined as the two-fold problem of supporting expeditionary operating forces and dealing with water-stressed populations. To complete the analysis, however, we must state some assumptions, consistent with the anticipated future environment envisioned by the DOD service components and global trend analysis. One of the fundamental assumptions made is that the United States will not isolate itself from the international community but that it will continue to promote global security through both diplomatic and military actions. Other assumptions include that the world population will increase substantially over the next thirty years, that city centers and the littorals will become over populated, and that natural resources will become scarcer.

It is also necessary to make multiple assumptions regarding environmental factors that might affect military operations. Specifically, this paper makes the assumption that global climate change reports are accurate and reflect expected climatic events that will have an adverse effect on the environment. These events will cause sea levels to rise thereby reducing fresh water resources. Based on this assumption, it is further assumed that the combination of pollution and overuse from growing populations will exacerbate depletion of water stores and push water stressed states into water scarcity. For these reasons, internal and external conflict is likely to occur as fragility[viii] increases and countries fight for limited resources.

If population growth skyrockets and conflict is likely to increase, it is expected that states will take steps to secure their borders from potential influxes of displaced persons or from state, non-state, and transnational threats. As such, these countries, having access to new technology, are likely to increase their A2/AD capabilities as a matter of protection. With this scenario in mind, DOD concepts have painted an accurate picture regarding the future operating environment, where A2/AD threats and the tactical and operational challenges of urban warfare will require limited presence in the affected area. US and allied forces will need to operate in a more disaggregated manner in order to avoid unintentional clashes with innocent civilians; however, they will also assume significant risk to their forces due to supply limitations. Thus,

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[viii] Fragility in this sense refers to both environmental and governmental instability. Environmental instability includes climatic events or human activity that causes negative changes in the ecosystem, reducing availability of clean water via aquifers, surface water, etc., negatively impacting agricultural, industrial, and individual consumption requirements. Governmental fragility includes the inability of a government to provide essential services (i.e. safe water) for the population in addition to an inability to enforce laws.

the military problem is framed from a perspective of operating divorced from a base and without consistent logistics resupply.

Part II: Finding a Solution

Chapter 5: A Conceptual Framework for a Solution

If we are all thinking alike, then no one is thinking.

- John Wooden, Head Basketball Coach, UCLA

While the United States military, over the past 40 years or more, has conducted mostly contingency response, shows of force, and noncombatant extraction operations due to political or natural events, and the DOD over the past 16 years has had their hands tied supporting the "war on terrorism" in Iraq and Afghanistan, the FOE, as currently anticipated, will place extraordinary demands on the US Joint Force. These challenges generate a clear requirement for lighter and leaner forces, capable of rapid deployment, effective employment, and sustainment, with greater dispersion over long distances.

Moreover, the Deputy Commandant, Installations and Logistics (DC, I&L) identified two challenges of logistical support in an October 2016 article in the Marine Corps Gazette. First, A2/AD threats will end massing of logistics ashore which is a key vulnerability to overcome; and second, current military systems are big and heavy and require lots of logistics support.[41] Specifically, he states, “our potential adversaries’ A2/AD capabilities …will require us to have a force that is more distributed. When this force disaggregates and aggregates in the littorals, our operating concept, doctrine, capability, and capacity must enable us to rapidly move, maneuver, and reposition. That force will require “modular” logistical capabilities.”[42] Keeping this in mind, the below chart provides a conceptual framework to inculcate hybrid logistics into the mind of logisticians.[ix]

[ix] DC, I&L describes hybrid logistics as an evolution in logistical affairs and more specifically states that it is the ability to use conventional capabilities while leveraging new technology and concepts.

Logistics Sustainment and Generation Matrix

	Reduce	Reclamation	Forage	Produce	Resupply
Fuel and Power	Minimize electrical device usage to military necessity	Collect C02 emitted from generators	Contract for local sources of energy (power grid and/or available fuel stocks)	Use solar panels with battery backup and microgrid to collect sunlight for use. Use recycled water and atmospherically collected CO2 to produce hydrocarbon fuel	Receive resupply of water and CO2 via airdrop and convert to hydrocarbon fuel locally
Water	**Operate, when possible during cooler parts of the day**	**Retain and Reuse gray and black water**	**Water harvesting, desalinization, contract for a well if feasible.**	**Bring equipment to harvest water (relative humidity) from the atmosphere or desalinate non-potable water**	**Transport water from a logistics storage facility/asset (point).**
Food	Focus on food with high-calorie content	Use food scraps for methane digester	Determine if local flora or fauna is edible without disturbing local economy	Use vertical farm in an (ISO) to produce limited fresh produce	Transport food from a logistics storage facility
Medical Supplies	Emphasize proper hygiene and safe individual practices such as sexual contact, air and waterborne disease	Biodegradable medical supplies could be placed in a methane digester, plastics and metals would need to be sterilized and shredded before re-use	Acquire and store blood from US service members as able depending on military operations.	Re-use metal and plastics (sterilized) as feeder stock for 3D printers for medical and surgical tools. Use artificial blood substitutes[14]	Transport from a logistics storage facility
Spare Parts	Conduct proper preventative maintenance checks and services.	Shred metal parts for use by 3d printer to make new parts	Determine if there are junkyards or scrap materials in local area for shredder	Use 3d printer to produce spare parts on site	Receive stock supply for 3d metal or plastic printer, and any mission essential parts such as microprocessors not producible with 3d printer
Ammunition	Emphasize fire discipline Maximize use of weapons systems with standard ammo	Save expended brass casing for re-use as feedstock for 3d printers	Obtain metal feeder stock for 3d printers	3D print ammunition	Transport ammunition from storage point

Figure 1, Advance Studies Program Group 1: A Conceptual Framework of Logistical Requirements for Places without Bases

The conceptual framework offers methods to reduce, recycle, resupply and create (forage/produce). The idea is to give commanders a way to determine key performance indicators (KPI) and key performance parameters (KPP) to balance mission requirements across the ROMO.[43]

Using water, for example, if the commander requires 2L/d per person, he can use the matrix to determine the best system to support the requirement. If reduction is selected, personnel within the operating environment can operate in cooler parts of the day; thereby reducing the overall water requirement. This approach still requires a sustainable source of fresh water to replenish troops as needed. If the commander chooses to resupply, the cost of water will increase substantially. Specifically, the additional "tail" of logistics: fuel for trucks or aircraft, personnel to operate and transport, and time to move the water can increase the price point of the water. This option also increases potential risk to personnel and equipment that must traverse the operating environment to deliver the required support.

In a mature theater where distribution networks exist, these options may be the most cost effective (particularly if there is access to water). Conversely, in a mature theater where EABs are not vulnerable, because of the problems or threats noted in this paper, these methods may not be viable. At this point, the commander can use the matrix and supporting “modular” hybrid logistics capabilities explained later in this paper, to accomplish his mission.

Chapter 6: From Present to Future Water Technology

The Present Method of Water Supply and Resupply

The days when a person could drink water directly from a stream or a fresh body of water are long gone. As the world's population grew, pollution soon followed. People actually began purification techniques in 2000 BC. According to Lenntech[x], based on ancient Greek and Indian writings, most people understood basic water purification techniques to kill bacteria in the water.[44] Between 1939 and 1945, the United States Army Corps of Engineers began water purification missions using disinfectants and pumps to provide potable water to their troops.[45] Unfortunately, industrial and chemical runoff into ground water or other fresh water sources have rendered those techniques obsolete.

The United States Army and Marine Corps later used more modern techniques to sanitize and distribute water. Two publications – the Army's Field Manual (FM) 10-52-1, "Water Supply Point Equipment and Operations," and Marine Corps Warfighting Publication (MCWP) 4-11.6, "Petroleum and Water Logistics Operations" -- provide detailed instructions to service members regarding water point determination, storage, and distribution operations.

These techniques include systems that focus on purification or desalinization (mostly aboard Naval vessels) of water; however, the system must be near a water source in order for it to work. The Lightweight Water Purifier; Reverse Osmosis Water Purification Unit (ROWPU); and Tactical Water Purification System (TWPS) exists in either the Army or Marine Corps inventory to purify water. For distribution, a number of systems can be used: the Tactical Water Distro System (TWDS) with a ten-mile hose line set; both the three or five thousand Semi-Trailer Mounted Fabric Tank (SMFT); the Forward Area Water Point Supply System

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[x] Lenntech is a water treatment company located in the Netherlands. They design, engineer, manufacture, install, maintain, and train water purification techniques for domestic and industrial needs.

(FAWPSS); 400 Gallon Water Trailer M149A2 Water Trailer, Camel 800 Gallon Water Trailer, or the Hippo 2000 Gallon Tank Rack. The Storage Systems (SDS) Storage & Distro Systems consist of twenty or fifty thousand-gallon bags; and the Onion Bag is a three thousand-gallon, thin skinned bag used for temporary storage.

Any of the abovementioned systems offer the operating force sufficient water for operations. Both organizations have the capability to conduct water operations, but as outlined by writer, Lieutenant Colonel James S. Moore in his Master's Thesis, "The U.S. Military's Reliance on Bottled Water During Military Operations," which lists multiple examples where an army had to overcome water scarcity, they fail to do so.[46] Looking ahead to the future, however, we will see these systems and techniques rendered obsolete as the effects of the operating environment will deny the United States military access to water points required for purification efforts and will limit the ability to conduct resupply operations.[xi]

The FOE will also directly challenge, writer, Lieutenant Colonel Moore's assessment of the utility of creating dams to give the commander operational reach and reduce the need for

[xi] Excerpt from LtCol Moore's writing: 1096 AD - The Turks defeated the so-called People's Crusade, as they ran out of water and had to surrender. Their supply lines were cut and they were forced to drink the blood of donkeys and their own urine to survive. 1812 – Napoleon lost thousands of his forces to water-borne typhus and dysentery during the ill-fated Russian campaign. 1917 – British General Edmund Allenby had to find ways to support his forces with water during his World War I campaign in Palestine. 1939 – 1945 – U.S. Army Corps of Engineers were responsible for the water supply mission. The 518th Engineer Water Supply Company located water sources, tested and purified water, and supervised distribution to the troops. The other armed forces and services usually provided their own trucks to haul water from Engineer water points. In North Africa, for example, the Engineer Company "found multiple water points and - using a series of pumps, chemical disinfectants and 3,000-gallon collapsible canvas tanks for temporary storage - played a critical role during the Allied drive through Tunisia. On its peak day, the 518th distributed 72,840 gallons of water. 1967 – Arab – Israeli War, many Egyptian soldiers were cut off from their units and had to walk about 200 kilometers through the hot sand by foot before reaching the Suez Canal, all with limited supplies of food and water while being exposed to intense heat. Thousands of Soldiers died as a result. Many Egyptian Soldiers chose instead to surrender to the Israelis. The Israeli soldiers were trained to drink a liter of water per hour, which made their fighting force competitively better prepared for this battle. 1990 – During Operation Desert Shield/Storm, U.S. Army Quartermaster water supply units deployed to support U.S. forces involved in the operation. The units deployed with Reverse Osmosis Water Purification Units (ROWPUs) and collapsible water storage tanks and drums. "…they ensured that no Allied troops lacked adequate supplies of fresh water."

bottled water. While his assessment may have been valid at the time, the FOE 2025 and beyond will require a more versatile capability, not limited to geographical features, and certainly not something that will divert existing bodies of water (specifically for water rights issues previously discussed).

The Future of Water Supply

The FOE will require a more dynamic, mobile, and autonomous force that can survive on extended lines of communications for long periods of time. The programs of record in both the United States Army and Marine Corps will not offer the capability and versatility required of maneuver forces. As such, the DOD must invest in new technology and create hybrid logistics capabilities within each service.

In the past, several years, scientists have made many strides towards water purification and creation due to the increasingly water scarce environment. These new options, or systems, made to DOD specifications can provide the commander better options to ensure adequate hydration. The new Fontus water bottle is one example.[xii] The bottle is designed to refill itself through relative humidity in the air. At its core is a condenser (used like a cooler) connected to hydrophobic surfaces that repel the water. The bottle is powered by a small solar panel that attaches to the outside of the bottle like a sleeve, and as it takes in air, the surfaces get cold, and condensation occurs.[47]

Another interesting technology is Graphene. Discovered by early 20th century science, graphene is considered a miracle material with multiple applications.[48] To start, graphene is a two-dimensional, one atom thick mesh of carbon atoms "densely packed in a honeycomb lattice".[49] It is considered a "miracle material" because of its attributes: thin and light, stronger

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[xii] Fontus.at/about: Fontus is a young star-up company of engineers and industrial designers who developed the Fontus bottle. A patent is pending for the Fontus Airo and Fontus Ryde – both are self-filling water bottles.

than steel, conducts ten times faster than copper and can carry more electricity, to name a few. Its structure allows "optical, thermal, mechanical, and electrical" properties. Graphene is currently the subject of research in all industries to seek new application for its properties. Graphene can revolutionize entire industries, to include clean energy, new electronics, and clean water. In a UN report, researchers cleaned water using a simple device resulting in water, "totally pure and free from all salts, metal ions, and heavy materials."[50]

Disadvantages

Using a solar based system as a way to conserve or generate energy has multiple limitations.

1. If DOD conducts operations during periods of low visibility (night operations), the solar panels will not receive the sunlight required to operate the condenser.
2. The military cannot stop operations in order to expose the solar panels to direct sunlight.
3. If the relative humidity is lower than 20 percent, nothing will condense.
4. To create a system such as this is too expensive.

Graphene is very new and all of the limitations are unknown. However, from what is available in research, the disadvantages of graphene are:

1. It is a great conductor of electricity but researches have not created a switch.
2. Graphene is susceptible to oxidative environments.
3. "Research has proven that graphene exhibits some toxic qualities. Scientists discovered that graphene features jagged edges that can easily pierce cell membranes, allowing it to enter into the cell and disrupt normal functions".[51]

Advantages

Generally speaking, the advantage of using both technologies in an individual or modular, unit purification system outweighs the disadvantages. To mitigate energy concerns, DOD can create a similar individual hydration system that uses both solar technology and friction (as a source of electro-static energy) from a person's movement. The energy from either source can be stored in a small, lightweight converter until the system requires the energy to create water. Relative humidity may be a little trickier, but in most environments, whether it be temperate or arid, the temperature decreases and humidity increases at night. While the individual system cannot be used during the day, a unit sized system can create water through the night for use in the day.

The disadvantages of graphene can be challenging to overcome. But as previously discussed, scientists in all industries are conducting research for new applications and to improve current proposed uses for the material. Individual and unit systems can be designed to prevent graphene from direct contact with air (a closed system), thereby reducing the risk for oxidation, that contributes to graphene exposure.

If the disadvantages of both technologies are mitigated, the DOD can create a system that will allow full use of the conceptual logistics framework suggested earlier in the paper. Specifically, the system will:

1. Reduce resupply missions
2. Reduce overall cost of operations (reduction of resupply missions reduces fuel consumption)
3. Reduce risk to personnel (less need for convoys)

4. Allow the DOD to operate in the most austere environments with or without a base and definitely without an "Iron Mountain" of supplies ashore.

Conclusion

The FOE is described as a complex, multi-domain environment where state, non-state, and transnational threats will proliferate and intensify. The environmental drivers of instability, which include population growth, economic competition, and social orientation, will create an atmosphere where additional drivers and forecasts of the FOE from DOD wide and service capstone concepts will be realized.

Population growth spurts or the effects of global warming can cause water insecurity, affecting the global economy and social systems. As these situations worsen, new technology to overcome the challenges will further exacerbate tensions within affected regions. These tensions will give rise to proliferation of weapons of mass destruction and nuclear arms as protection measures.

The disorder and instability will require United States intervention, but A2/AD threats, will preclude access to infrastructure ashore. Therefore, DOD must have an agile force that is capable of rapid deployment and redeployment into a theater of operations. It must also have the ability to provide logistics support over longer distances without massive buildup of logistics ashore.

A critical requirement for operations is water. In regions of current or impending water scarcity, is the DOD must not worsen the situation upon entry in the theater of operations. Therefore, the current systems used to provide potable water for service members may become ineffective if the conditions suggested in the services' capstone concepts develop. Specifically, each system requires an existing body of water which may not be available. However, if the services adopt the recommended logistics conceptual framework, leaders could use each consideration to gain an advantage over the adversary.

The bottom line is, if DOD uses new technology and hybrid logistics to support requirements, i.e. parts, ammunition, and water, using the conceptual framework, this will allow troops to operate in the FOE and will greatly reduce the logistics tail.

Appendix A:
Total Population by Country, 1950, 2015, 2030, 2050, and 2100 (Medium Variant)[xiii]

	Population (thousands)				
Country or area	1950	2015	2030	2050	2100
World	**2 525 149**	**7 349 472**	**8 500 766**	**9 725 148**	**11 213 317**
Afghanistan	7 752	32 527	43 852	55 955	57 638
Albania	1 263	2 897	2 954	2 710	1 755
Algeria	8 872	39 667	48 274	56 461	61 060
American Samoa	19	56	57	57	40
Andorra	6	70	71	72	60
Angola	4 355	25 022	39 351	65 473	138 738
Anguilla	5	15	16	15	11
Antigua and Barbuda	46	92	105	114	114
Argentina	17 150	43 417	49 365	55 445	58 572
Armenia	1 354	3 018	2 993	2 729	1 793
Aruba	38	104	107	102	84
Australia	8 177	23 969	28 482	33 496	42 389
Austria	6 936	8 545	8 844	8 846	8 335
Azerbaijan	2 896	9 754	10 727	10 963	9 636
Bahamas	79	388	446	489	498
Bahrain	116	1 377	1 642	1 822	1 602
Bangladesh	37 895	160 996	186 460	202 209	169 541
Barbados	211	284	290	282	259
Belarus	7 745	9 496	8 977	8 125	6 916
Belgium	8 628	11 299	12 019	12 527	13 210
Belize	69	359	472	588	677
Benin	2 255	10 880	15 593	22 549	35 544
Bermuda	37	62	59	54	42
Bhutan	177	775	886	950	793
Bolivia (Plurinational State of)	3 090	10 725	13 177	15 963	18 118
Bosnia and Herzegovina	2 661	3 810	3 584	3 069	1 919
Botswana	413	2 262	2 817	3 389	3 681
Brazil	53 975	207 848	228 663	238 270	200 305
British Virgin Islands	7	30	35	38	36
Brunei Darussalam	48	423	496	546	489
Bulgaria	7 251	7 150	6 300	5 154	3 406
Burkina Faso	4 284	18 106	27 244	42 789	80 990
Burundi	2 309	11 179	17 357	28 668	62 662
Cabo Verde	178	521	614	707	680
Cambodia	4 433	15 578	18 991	22 545	23 928
Cameroon	4 466	23 344	32 947	48 362	82 382
Canada	13 737	35 940	40 390	44 136	49 668
Caribbean Netherlands	7	25	28	30	32
Cayman Islands	6	60	71	82	99
Central African Republic	1 327	4 900	6 490	8 782	12 515
Chad	2 502	14 037	21 946	35 131	68 927
Channel Islands	102	164	174	181	182
Chile	6 143	17 948	20 250	21 601	19 744
China	544 113	1376 049	1415 545	1348 056	1004 392
China, Hong Kong SAR	1 974	7 288	7 951	8 148	7 924

xiii United Nations, World Populations Prospects: The 2015 Revision, Key Findings and Advance Tables, 18

Appendix A:

Country or area	1950	2015	2030	2050	2100
China, Macao SAR	196	588	720	838	1 023
Colombia	12 341	48 229	53 175	54 927	45 321
Comoros	156	788	1 081	1 502	2 307
Congo	808	4 620	6 790	10 732	22 015
Cook Islands	15	21	23	24	21
Costa Rica	959	4 808	5 413	5 759	4 993
Côte d'Ivoire	2 630	22 702	32 143	48 797	101 154
Croatia	3 850	4 240	3 977	3 554	2 615
Cuba	5 920	11 390	11 237	10 339	7 103
Curaçao	100	157	175	189	208
Cyprus	494	1 165	1 300	1 402	1 386
Czech Republic	8 903	10 543	10 461	9 965	8 774
Dem. People's Rep. of Korea	10 549	25 155	26 701	26 907	24 842
Dem. Republic of the Congo	12 184	77 267	120 304	195 277	388 733
Denmark	4 268	5 669	6 003	6 299	6 838
Djibouti	62	888	1 054	1 186	1 126
Dominica	51	73	76	74	52
Dominican Republic	2 365	10 528	12 087	13 238	12 027
Ecuador	3 470	16 144	19 563	23 013	24 499
Egypt	20 897	91 508	117 102	151 111	200 802
El Salvador	2 200	6 127	6 408	6 390	4 420
Equatorial Guinea	226	845	1 238	1 816	2 984
Eritrea	1 142	5 228	7 311	10 421	15 616
Estonia	1 101	1 313	1 243	1 129	904
Ethiopia	18 128	99 391	138 297	188 455	242 644
Faeroe Islands	32	48	50	52	52
Falkland Islands (Malvinas)	2	3	3	3	3
Fiji	289	892	940	924	696
Finland	4 008	5 503	5 706	5 752	5 857
France	41 880	64 395	68 007	71 137	75 998
French Guiana	25	269	381	546	891
French Polynesia	60	283	313	330	297
Gabon	473	1 725	2 321	3 164	4 466
Gambia	271	1 991	3 105	4 981	8 896
Georgia	3 527	4 000	3 868	3 483	2 438
Germany	69 786	80 689	79 294	74 513	63 244
Ghana	4 981	27 410	36 865	50 071	73 033
Gibraltar	20	32	33	32	28
Greece	7 566	10 955	10 480	9 705	7 393
Greenland	23	56	57	52	41
Grenada	77	107	112	110	72
Guadeloupe	210	468	491	498	437
Guam	60	170	200	228	242
Guatemala	3 146	16 343	21 424	27 754	34 812
Guinea	3 094	12 609	18 276	27 486	49 049
Guinea-Bissau	535	1 844	2 541	3 564	5 489
Guyana	407	767	821	806	595
Haiti	3 221	10 711	12 578	14 189	13 544

Total Population by Country, 1950, 2015, 2030, 2050, and 2100 (Medium Variant)[xiv]

[xiv] Source, United Nations, World Populations Prospects: The 2015 Revision, Key Findings and Advance Tables, 19

Appendix A:

Country or area	1950	2015	2030	2050	2100
Holy See	1	1	1	1	1
Honduras	1 487	8 075	9 737	11 217	10 646
Hungary	9 338	9 855	9 275	8 318	6 506
Iceland	143	329	364	389	384
India	376 325	1311 051	1527 658	1705 333	1659 786
Indonesia	69 543	257 564	295 482	322 237	313 648
Iran (Islamic Republic of)	17 119	79 109	88 529	92 219	69 637
Iraq	5 719	36 423	54 071	83 652	163 905
Ireland	2 913	4 688	5 204	5 789	6 372
Isle of Man	55	88	96	104	114
Israel	1 258	8 064	9 998	12 610	17 285
Italy	46 599	59 798	59 100	56 513	49 647
Jamaica	1 403	2 793	2 867	2 710	1 704
Japan	82 199	126 573	120 127	107 411	83 175
Jordan	449	7 595	9 109	11 717	14 147
Kazakhstan	6 703	17 625	20 072	22 447	24 712
Kenya	6 077	46 050	65 412	95 505	156 856
Kiribati	33	112	142	178	244
Kuwait	152	3 892	4 987	5 924	6 484
Kyrgyzstan	1 740	5 940	7 097	8 248	9 046
Lao People's Dem. Republic	1 683	6 802	8 489	10 172	10 411
Latvia	1 949	1 971	1 806	1 593	1 278
Lebanon	1 335	5 851	5 292	5 610	4 741
Lesotho	734	2 135	2 486	2 987	3 548
Liberia	930	4 503	6 414	9 436	15 977
Libya	1 113	6 278	7 418	8 375	8 144
Liechtenstein	14	38	41	43	47
Lithuania	2 567	2 878	2 655	2 375	2 013
Luxembourg	296	567	678	803	1 030
Madagascar	4 084	24 235	35 960	55 294	105 499
Malawi	2 954	17 215	26 584	43 155	87 056
Malaysia	6 110	30 331	36 107	40 725	40 778
Maldives	74	364	437	494	438
Mali	4 708	17 600	27 370	45 404	92 981
Malta	312	419	428	411	348
Marshall Islands	13	53	56	67	75
Martinique	222	396	391	358	289
Mauritania	660	4 068	5 666	8 049	13 059
Mauritius	493	1 273	1 310	1 249	952
Mayotte	15	240	344	497	752
Mexico	28 013	127 017	148 133	163 754	148 404
Micronesia (Fed. States of)	32	104	118	129	116
Monaco	20	38	40	44	55
Mongolia	780	2 959	3 519	4 028	4 487
Montenegro	395	626	618	574	437
Montserrat	14	5	5	5	5
Morocco	8 986	34 378	39 787	43 696	40 888
Mozambique	6 313	27 978	41 437	65 544	127 648

Total Population by Country, 1950, 2015, 2030, 2050, and 2100 (Medium Variant[xv])

[xv] Source, United Nations, World Populations Prospects: The 2015 Revision, Key Findings and Advance Tables, 20

Appendix A:
Total Population by Country, 1950, 2015, 2030, 2050, and 2100 (Medium Variant)[xvi]

Country or area	1950	2015	2030	2050	2100
Myanmar	17 527	53 897	60 242	63 575	56 026
Namibia	485	2 459	3 272	4 322	5 730
Nauru	3	10	11	11	9
Nepal	8 483	28 514	33 104	36 159	29 677
Netherlands	10 027	16 925	17 605	17 602	17 220
New Caledonia	65	263	311	363	419
New Zealand	1 908	4 529	5 103	5 607	6 094
Nicaragua	1 295	6 082	7 033	7 863	6 996
Niger	2 560	19 899	35 966	72 238	209 334
Nigeria	37 860	182 202	262 599	398 508	752 247
Niue	5	2	2	2	2
Northern Mariana Islands	7	55	56	51	29
Norway	3 265	5 211	5 945	6 658	7 845
Oman	456	4 491	5 238	5 844	5 751
Pakistan	37 542	188 925	244 916	309 640	364 283
Palau	7	21	25	28	29
Panama	860	3 929	4 781	5 599	6 012
Papua New Guinea	1 708	7 619	10 057	13 240	17 951
Paraguay	1 473	6 639	7 845	8 895	8 665
Peru	7 728	31 377	36 855	41 899	41 557
Philippines	18 580	100 699	123 575	148 260	168 618
Poland	24 824	38 612	37 207	33 136	22 289
Portugal	8 417	10 350	9 845	9 216	7 407
Puerto Rico	2 218	3 683	3 638	3 367	2 212
Qatar	25	2 235	2 781	3 205	3 170
Republic of Korea	19 211	50 293	52 519	50 593	38 504
Republic of Moldova	2 341	4 069	3 839	3 243	1 856
Réunion	248	861	947	989	870
Romania	16 236	19 511	17 639	15 207	10 700
Russian Federation	102 799	143 457	138 652	128 599	117 445
Rwanda	2 186	11 610	15 785	21 187	25 692
Saint Helena	5	4	4	4	3
Saint Kitts and Nevis	46	56	63	68	63
Saint Lucia	83	185	202	207	168
Saint Pierre and Miquelon	5	6	7	7	7
St. Vincent and the Grenadines	67	109	112	109	77
Samoa	82	193	210	241	262
San Marino	13	32	33	33	30
Sao Tome and Principe	60	190	256	353	538
Saudi Arabia	3 121	31 540	39 132	46 059	47 586
Senegal	2 477	15 129	22 802	36 223	75 042
Serbia	6 732	8 851	8 281	7 331	5 334
Seychelles	36	96	101	100	81
Sierra Leone	1 944	6 453	8 598	11 392	14 489
Singapore	1 022	5 604	6 418	6 681	5 593
Sint Maarten (Dutch part)	1	39	46	52	63
Slovakia	3 437	5 426	5 353	4 892	3 732
Slovenia	1 473	2 068	2 054	1 942	1 693

[xvi] Source, United Nations, World Populations Prospects: The 2015 Revision, Key Findings and Advance Tables, 21

Appendix A:

Country or area	1950	2015	2030	2050	2100
		Population (thousands)			
Country or area	1950	2015	2030	2050	2100
Solomon Islands	90	584	757	992	1 354
Somalia	2 264	10 787	16 493	27 030	58 311
South Africa	13 683	54 490	60 034	65 540	65 696
South Sudan	2 583	12 340	17 810	25 855	41 752
Spain	28 070	46 122	45 920	44 840	38 337
Sri Lanka	8 076	20 715	21 536	20 836	14 857
State of Palestine	932	4 668	6 765	9 791	15 516
Sudan	5 734	40 235	56 443	80 284	127 328
Suriname	215	543	599	624	548
Swaziland	273	1 287	1 507	1 792	2 082
Sweden	7 010	9 779	10 766	11 881	14 470
Switzerland	4 668	8 299	9 223	10 019	11 245
Syrian Arab Republic	3 413	18 502	28 647	34 902	38 098
Tajikistan	1 532	8 482	11 102	14 288	18 559
TFYR Macedonia	1 254	2 078	2 078	1 938	1 487
Thailand	20 710	67 959	68 250	62 452	41 604
Timor-Leste	433	1 185	1 577	2 162	3 234
Togo	1 395	7 305	10 489	15 681	27 873
Tokelau	2	1	1	2	2
Tonga	47	106	121	140	159
Trinidad and Tobago	646	1 360	1 372	1 291	984
Tunisia	3 605	11 254	12 686	13 476	12 494
Turkey	21 238	78 666	87 717	95 819	87 983
Turkmenistan	1 211	5 374	6 160	6 555	5 606
Turks and Caicos Islands	5	34	42	48	52
Tuvalu	5	10	11	11	11
Uganda	5 158	39 032	61 929	101 873	202 868
Ukraine	37 298	44 824	40 892	35 117	26 400
United Arab Emirates	70	9 157	10 977	12 789	13 389
United Kingdom	50 616	64 716	70 113	75 361	82 370
United Republic of Tanzania	7 650	53 470	82 927	137 136	299 133
United States of America	157 813	321 774	355 765	388 865	450 385
United States Virgin Islands	27	106	106	97	69
Uruguay	2 239	3 432	3 596	3 667	3 258
Uzbekistan	6 945	29 893	34 397	37 126	32 077
Vanuatu	48	265	354	476	677
Venezuela (Bolivarian Republic of)	5 482	31 108	36 673	41 562	41 927
Viet Nam	24 810	93 448	105 220	112 783	105 076
Wallis and Futuna Islands	7	13	13	13	12
Western Sahara	14	573	738	901	1 047
Yemen	4 402	26 832	36 335	47 170	50 826
Zambia	2 317	16 212	25 313	42 975	104 869
Zimbabwe	2 747	15 603	21 353	29 615	40 263
Other non-specified areas	7 562	23 381	23 116	20 778	12 518

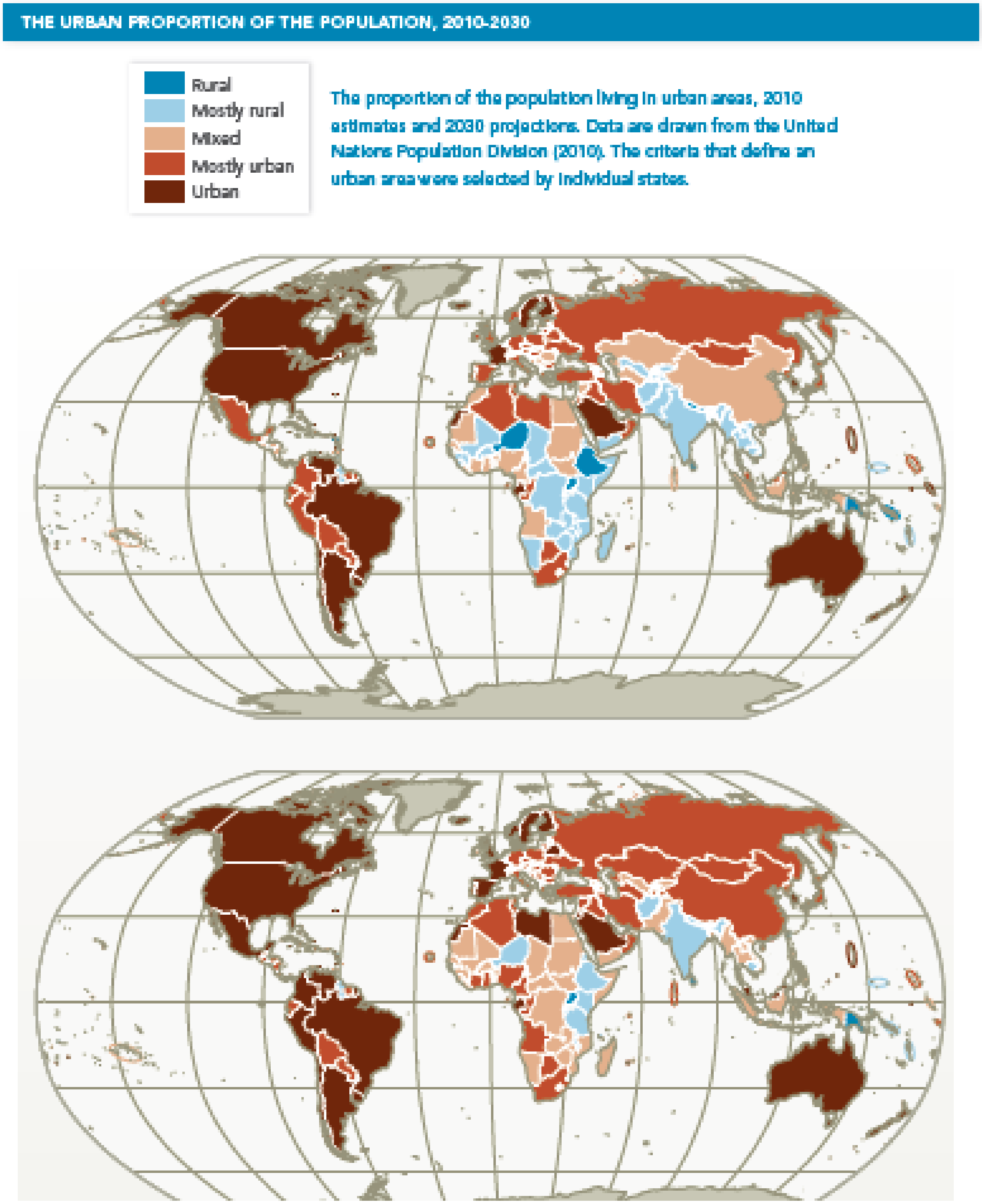
Source: United Nations, Department of Economic and Social Affairs, Population Division (2015). *World Population Prospects: The 2015 Revision*. New York: United Nations.

Total Population by Country, 1950, 2015, 2030, 2050, and 2100 (Medium Variant)[xvii]

[xvii] Source, United Nations, World Populations Prospects: The 2015 Revision, Key Findings and Advance Tables, 22

Appendix B

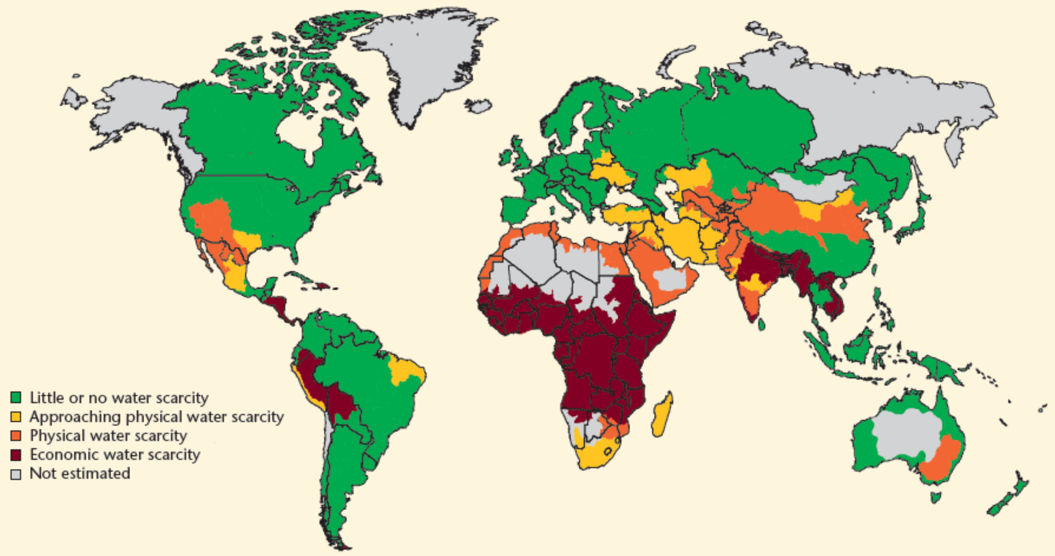
Urban Population Distribution[xviii]



[xviii] Source: Global Trends 2030: Alternative Worlds, 28

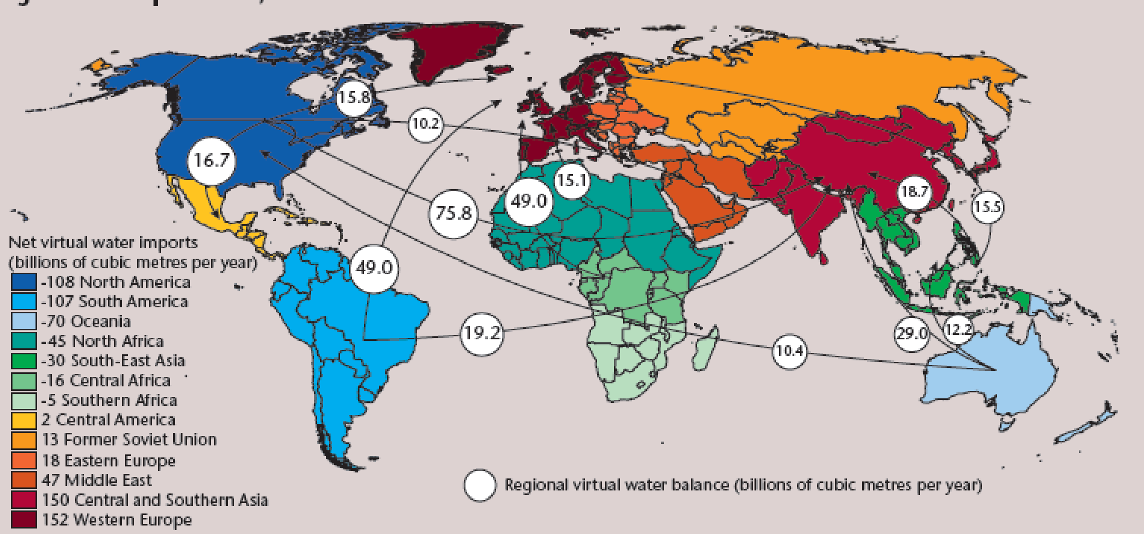
Appendix C
Projected Global Water Scarcity and Virtual Water Flows related to trade
[xix]

Map 8.1 **Increasing water scarcity**



Source: Based on Comprehensive Assessment of Water Management in Agriculture 2007.

Regional virtual water balances and net interregional virtual water flows related to trade in agricultural products, 1997-2001

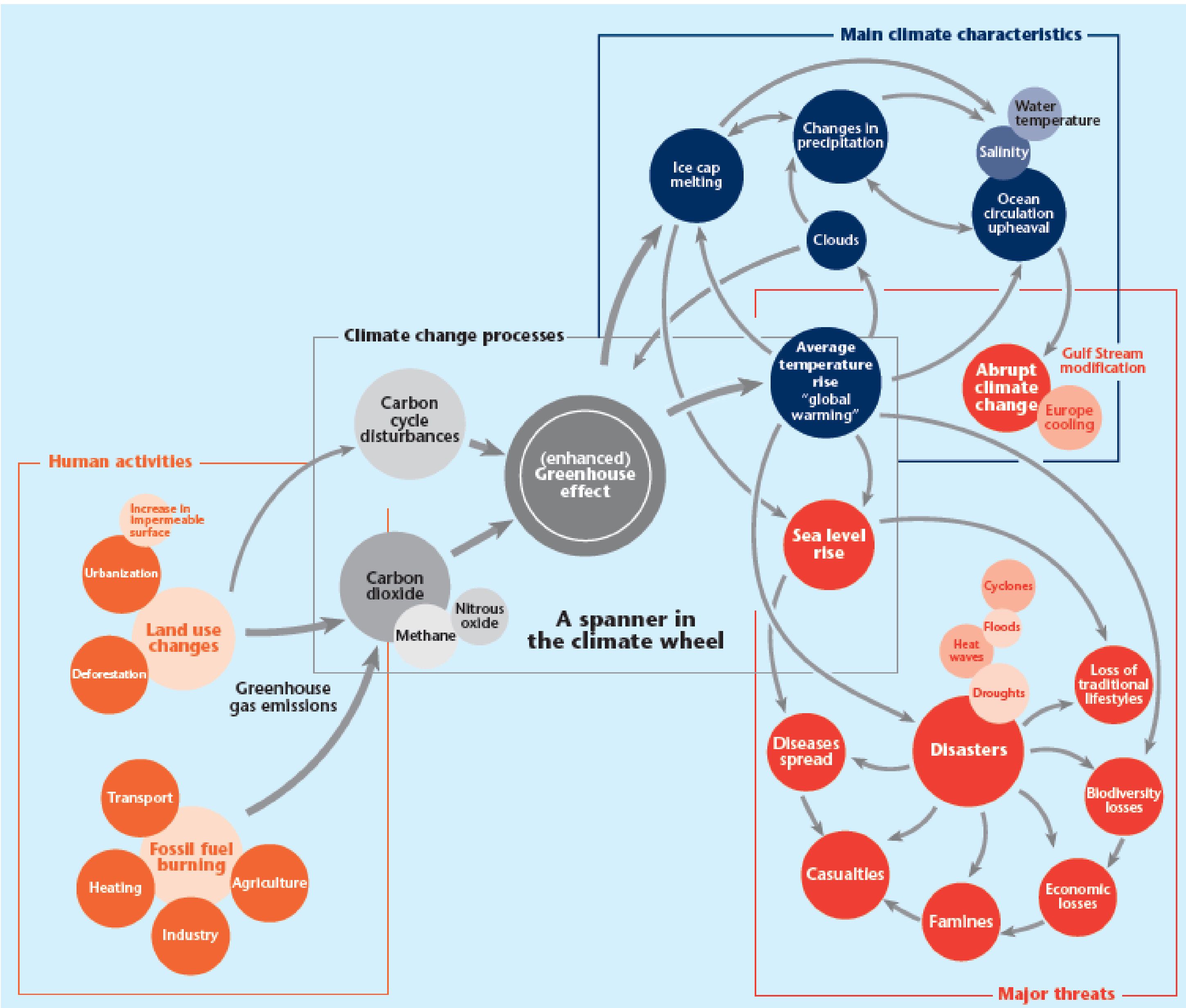


Source: Based on Hoekstra and Chapagain 2008.

[xx]

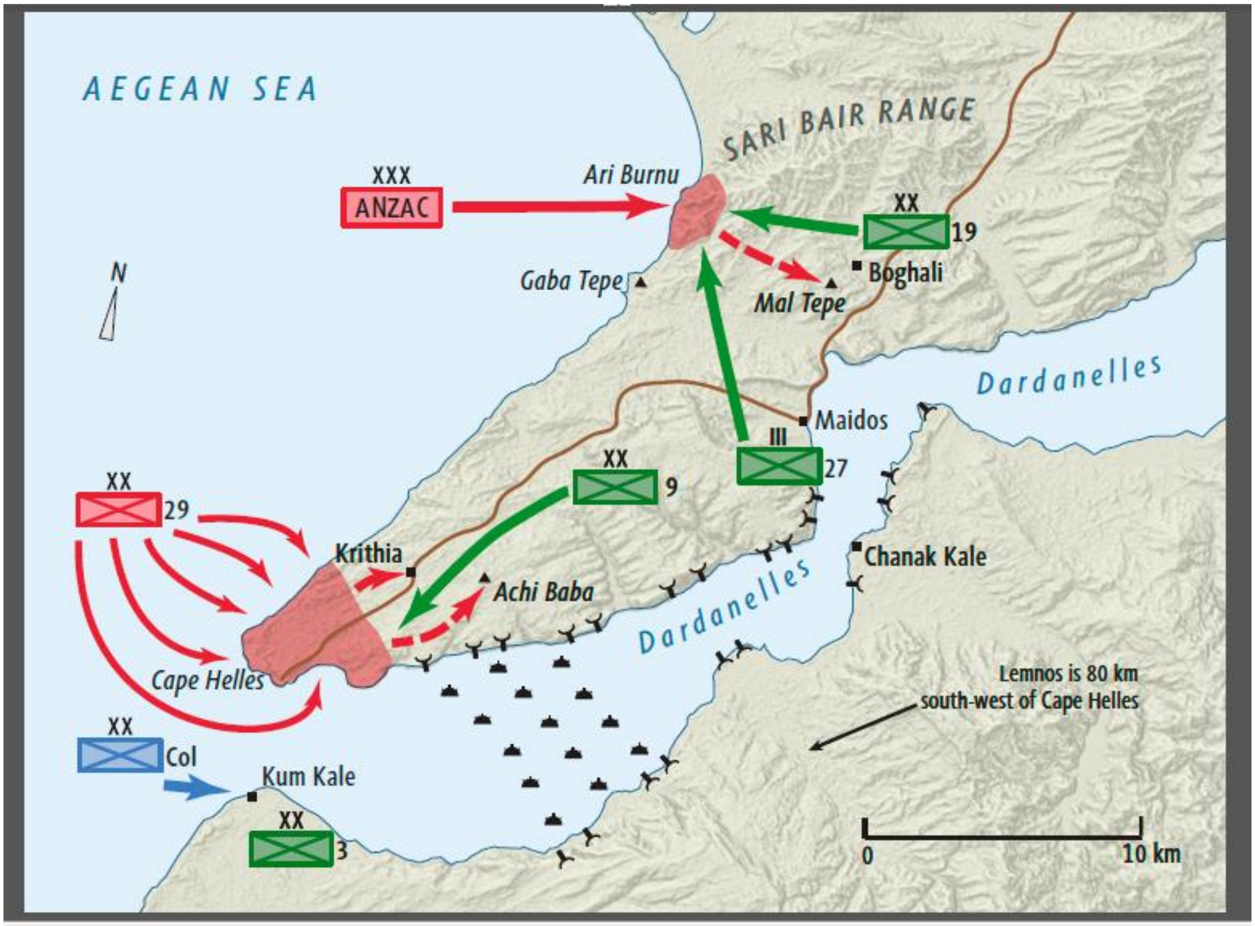
[xix] Water in a Changing World, 128
[xx] Water in a Changing World, 35

Appendix D
Climate Change: Process, Characteristics, and Threats[xxi]



[xxi] United Nations: World Water Development Report, based on UNFCCC 2007a., 69

Appendix E
Gallipoli Invasion Map and the Dardanelles Strait[xxii]



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