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A HISTORY OF WATER CANALS AND THEIR IMPACT ON THE ENVIRONMENT

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BY

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DEDICATION

To my beloved parents, Don and Dianne Recknagel, who instilled in me a lifelong love of learning. My fascination with history and geography came from their great minds.

ACKNOWLEDGMENTS

I wish to thank my four beloved daughters – Amber, Jade, Tawny, and Bella – for giving me the inspiration to complete a master's degree in history. They would have preferred I spend more time with them and less time on large academic projects like this. Yet they graciously encourage me to pursue higher education. I love my daughters with all my heart.

I thank Dr. John Chappo for his assistance throughout this thesis process. He helped me fine-tune my paper into a historical topic that represents importance in our modern world. I thank the reference librarians at Sunnyside Library for helping me locate information pertaining to this topic. Most of all I thank the Lord for giving us an amazing world to study.

PREFACE

I have long held an interest in water canals. I spent much of my childhood in central-eastern Washington State, home to a large irrigation network called the Columbia Basin Project. The project transformed the desert-like land into an agriculturally productive region. Fed by massive Grand Coulee Dam, the Columbia Basin Project holds prestige as the largest water reclamation project in United States history.

As teenagers we spent considerable time near the canals and reservoirs. In 1978 three young people from our community drowned near a human-made waterfall that served as part of the canal system. Drownings sometimes occurred in the canals themselves. Despite the dangers I understood the importance of the canal system. The ability of the project to alter the once-useless land into a dynamic agrarian industry captivated me.

Water canals still intrigue me. Initially I had planned to write this thesis on the economic and cultural impact of water canals. My professor suggested I change my focus. Within the burgeoning field of environmental history, he believed the historical impact of water canals on ecosystems would prove a more interesting topic. As a supporter of environmental issues, I enthusiastically agreed.

I had hoped to write about water canals in exotic, far-away lands like the Indus Valley and China. Yet finding appropriate materials on eastern regions proved difficult. I did however locate ample information on the Panama Canal and the Columbia Basin Project. This thesis therefore seems a bit Western Civilization-oriented. Hopefully another graduate student uncovers information to write about the environmental impact of water canals in eastern lands.

ABSTRACT OF THE THESIS

A HISTORY OF WATER CANALS AND THEIR IMPACT ON THE ENVIRONMENT

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Human-made water channels, commonly called canals, represent one of humankind's oldest and most important forms of technological achievements. People need water to exist, yet nature rarely supplies it in a flawless manner. The fluctuation of earth's hydrological cycle triggered devastating floods and droughts throughout history. In an effort to control water, humans dug artificial channels across land.

Research indicates that water canals, although crucial in the advancement of civilizations, ultimately led to environmental damage on landscapes and water regions. The irrigation canals of ancient Sumer led to the salinization of farmlands and the demise of its agricultural system. Constructing the Panama Canal caused incalculable damage to the fragile ecosystem of the tropical isthmus. The Columbia Basin Project in the State of Washington struggles to keep a balance between the natural environment and the interests of human industry.

Within the contextual study of environmental history, this thesis primarily examines the impact water canals had on three regions. It differs from existing historiography by analyzing the environmental impact of two primary types of canals: the Panama Canal, an interoceanic transport canal, and the Columbia Basin Project, an inland aqueduct canal system.

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INTRODUCTION

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People build two fundamental types of water canals. Transport canals, also called navigation or waterway canals, provide a means for vessels to carry humans and cargo. The other types of canals, called aqueduct canals, supply water itself to specific destinations. Aqueduct canals built to irrigate crops represent the earliest types of canals. Roughly 12,000 years ago during the Neolithic Revolution, humans achieved the ability to domesticate wild cereal grains. In an attempt to bring a steady water supply to those crops, farmers dug small, crude canals.[1]

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[1] Brian Fagan, *Elixir: A History of Water and Humankind* (New York: Bloomsbury Press, 2011), 115.

About 6,500 years ago ancient Sumerians built the earliest-known, big-scale canal system. Because of annual flooding from the Tigris and Euphrates rivers, the soil in this region proved exceptionally fertile. Yet those very floods destroyed entire villages. During dry seasons farmers struggled to provide vital water to their crops. In an effort to manage the highly erratic water supply, Sumerians developed an extensive canal system. Building and maintaining canals in this harsh region required considerable foresight, dedication, and skill. Over time a vast web of canals, weirs, and reservoirs transformed the bleak Sumerian landscape into endless rows of barley, wheat, and date palms.[2]

One form of technology often leads to new forms of technology. Using measuring rods and leveling-instruments, Sumerians developed significant skills as land surveyors. They also gained proficiency in boat-building, mapping, and advanced farming. Most notably, Sumerians invented a writing system. Starting as pictographs which led to cuneiform writing, Sumer holds prestige as the birthplace of the first true writing system in history. Writing mainly developed as a way of keeping records on mass food production. Later, writing also served as a means to pass complex irrigation techniques from one generation to the next.[3]

Dr. Samuel Noah Kramer, a leading scholar of ancient Sumer and its cuneiform writing took part in archaeological expeditions in southern Iraq. In his book *Sumerians: Their History, Culture, and Character*, Kramer revealed the finding of a remarkable clay document.[4] Written in about the eighteenth century BCE, the *Sumerian Farmers' Almanac* instructs farmers on plowing, harvesting, and irrigation. The document states, "When you are about to take hold of your field [for cultivation], keep a sharp eye on the openings of the dikes, ditches, and mounds

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[2] Ibid., 118; 114; 104; 112.

[3] Samuel Noah Kramer, *Sumerians: Their History, Culture, and Character* (Chicago: The University of Chicago Press, 1963), 104; 105.

[4] Ibid., 106-109.

[so that] when you flood the field the water will not rise too high in it. When you have emptied it of water, watch the field's water-soaked ground that it stay virile ground for you."[5] The almanac, one of the oldest comprehensive guides ever found, contained many more vital instructions on irrigation and successful crop production.

Sumerians also developed skills in mapmaking and diagrams. The *Schoyen Collection: 740 Manuscripts Spanning 5000 Years* contains a diagram (figure 1) created by a Mesopotamian canal engineer. Written on clay in cuneiform style, the diagram reveals a map of irrigation canals to the west of the Euphrates River in about 1684 – 1647 BCE. It provides the names of five main canals along with their lengths, widths, and depths. It reveals specific amounts of dredging planned for the main canals and their feeder canals. The *Schoyen Collection* also contains Sumerian diagrams detailing mathematical yields of wheat, barley, and other food products. More tablets describe wages allocated to farm laborers during harvests (figure 2).[6]

The establishment of water-rights, equitable distributions, and boundary lines led to a sophisticated administration system. Edicts required farmers to keep their basins and feeder canals excavated and cleaned at regular intervals. In fact laws demanded that everyone in the kingdom assist in building and maintaining canals. The complex irrigation system could only succeed if carried out as a large communal endeavor, not as an individual undertaking. This mutual enterprise led to a collective way of living and thinking. In time these factors initiated the establishment of humankind's earliest civilizations – the City-States of Sumer.[7]

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[5] Ibid., 340.

[6] Martin Schoyen, "MS3196: Map of Canals and Irrigation Systems to the West of Euphrates," (1684 – 1647 BC). *Schoyen Collection: 740 Manuscripts Spanning 5000 Years.* (2009), http://www.schoyencollection.com/smallercollect2.html#top Accessed on July 22, 2013.

[7] Kramer, *Sumerians: Their History, Culture, and Character*, 4; 5.

Innovations in agricultural technology continued to expand in Sumer. To increase crop production Sumerians devised at least two types of irrigation methods. Basin irrigation (figure 3) occurred from the release of canal water over entire fields, submerging them under a shallow layer of water. Furrow irrigation (figure 4) proved a more complicated process. It occurred when canal water inundated strips parallel to crop-growing fields. Preparing strip fields for furrow irrigation required the use of oxen-pulling scratch plows. Scratch plows came into use sometime before 3100 BCE and helped save large amounts of time and manpower.[8]

Sumerian canals did not enjoy the luxury of mechanical gates or sluices. Workers had to manually dig a gap on the sides of the embankment, allowing canal water to flow to crops. Workers then closed the gap by scooping mud into the opening again. To hoist water, Sumerians invented a shaduf, one of the earliest forms of a bucket and pulley (figure 5). They also invented an early form of a portable treadwheel to attain a back-and-forth or rotary motion of irrigated water.[9]

Farmers and laborers engaged in almost constant maintenance of canals. Water channels required slight but constant slopes to keep water flowing correctly. If slopes slanted too steeply, water eroded the banks. If slopes inclined too gently, silt and weeds built up, which blocked the channels.[10] Sumer lacked stone and wood to reinforce the canal banks. Instead, cane reeds woven into mats acted as reinforcing material. The need for cane reed produced an unusual institution – the rise of reed people (figure 6). Sumerians depended on the nearby marshes where the useful reed could grow.[11] "In many respects, the marsh areas during these early periods represented the

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[8] Fagan, *Elixir: A History of Water and Humankind*, 122; 123.

[9] Ibid., 59.

[10] Ibid.

[11] Sam A.A. Kubba, ed., *The Iraqi Marshlands and the Marsh Arabs: The Ma'dan, their Culture, and the Environment.* Reading, UK: Ithaca Press, 2011. http://site.ebrary.com/lib/apus/docDetail.action?docID=10457992. Accessed October 8, 2013.

'suburbs' of great cities like Ur, Uruk, Eridu, Lagesh, etc., in addition to the various mounds currently located in the marshes themselves."[12]

Sumerian myths reveal inherent connections with floods, marshes, reeds, and canals. The *Epic of Gilgamesh*, written in about 2,700 BCE, describes the odyssey of a mighty king. An excerpt from the flood chapter mentions the gods Ennugi as the Minister of Canals and the god Ea as the Clever Prince. Ea instructs Utanapishtim, a Noah-like figure, to tear down the reed houses and use the materials to build a boat for the upcoming flood.[13] The "Ur Nammu Stela" provides insight into a king's relationship with the divine world. Dated about 2,000 BCE, it shows King Ur Nammu commanding the digging of canals. Another scene reveals a female deity pouring canal water near the king.[14]

A Babylonian tale of creation makes several references to the god Marduk and his association to reeds and marshes; "Their waters commingling as a single body; No reed hut had been matted, no marsh land had appeared…"[15] Then, "Marduk laid a rush mat upon the face of the waters…," ". . . a swamp, he founded a marsh…Reeds he created…"[16] Another creation account describes famine and states, "The fields are not watered, There was no digging of [irrigation] ditches…"[17] This refers to gods and goddesses going on strike, refusing to dig more canals. The deities therefore created humans to perform work on canals.[18] The unknown author

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[12] Ibid., 92.

[13] "Story of the Flood," *The Epic of Gilgamesh.* http://www.ancienttexts.org/library/mesopotamian/gilgamesh/tab11.htm. Accessed October 8, 2013.

[14] Jeanny Vorys Canby, "A Monumental Puzzle: Reconstructing the Ur-Nammu Stela," *Expedition*, 29, (2001) *54 – 64*. http://www.penn.museum/documents/publications/expedition/PDFs/29-1/Monumental1.pdf. Accessed on July 22, 2013.

[15] *The Babylonian Legends of the Creation and the Fight Between Bel and the Dragon: As Told by Assyrian Tablets of Ninevah,* British Museum, 1921, p. 7-8. http://djvued.libs.uga.edu/BL1620xB7/1f/babylonian_legends_of_creation.pdf. Accessed October 8, 2013.

[16] Ibid.

[17] Kramer, *Sumerians: Their History, Culture, and Character*, 151-152.

[18] Ibid.

of the *Sumerian Farmers' Almanac* credits its information to a god named Ninurta, illustrating an inherent connection between irrigation, farming, and religion.

Sadly, modern scholars blame the use of irrigation canals as causing the demise of Sumer and its agricultural system. In his book *Elixir: A History of Water and Humankind*, Dr. Brian Fagan conveys, "Denser populations, and insatiable demands for more food, had led to year-round farming – and the shortening of critical fallow periods that had earlier helped leach salt from the soil."[19] *The Cambridge Encyclopedia of Archaeology* contains a brief sentence on the subject; "In the south [lands of Mesopotamia] dependence on irrigation also led to a greater level of agricultural stability, at least in the early periods of its development before the lack of drainage began to produce acute problems of salination."[20]

In *Water: The Epic Struggle for Wealth, Power, and Civilization*, the author delves further into the salinization of Sumerian soil. He points out the "…increased salt accumulations in the poorly drained soil had depleted its fertility and the ecosystem foundation of Mesopotamian civilization."[21] The author states that in an effort to cope with increasing salt in the soil, Sumerian farmers implemented alternative agricultural practices. For instance, in 3,500 BCE farmers grew roughly equivalent amounts of barley and wheat. Since growing barley proved more salt-resistant than growing wheat, by 2500 BCE barley represented 85 percent of crop production. In time however, conquering the salinity in the soil proved too challenging to overcome.[22]

[19] Fagan, *Elixir: A History of Water and Humankind*, 132.
[20] Andrew Sherratt, *The Cambridge Encyclopedia of Archaeology*, (New York: Cambridge University Press, 1980), 113.
[21] Steven Solomon, *Water: The Epic Struggle for Wealth, Power, and Civilization*, (New York: HarperCollins Publishers, 2010), 43.
[22] Ibid.

All natural water, including water defined as fresh, contains salts. The term salts refers to more than just salt found on a dinner table. It refers to several dissolved solids including carbonates, magnesium, sodium chloride, and sulfates of calcium. Mountain spring water, typically the most virginal water, emerges from its source containing very little salts. Mountain spring water contains about 50 parts per million of salts. As rivers and streams travel to the ocean they naturally pick up salts from eroded rocks and soil in riverbeds. At the end of their journeys, rivers pour their accumulation of salts into oceans. This process, occurring for the past hundreds of millions of years, accounts for the amassing of salts in today's oceans. Ocean water contains about 35,000 parts per million of salts.[23]

In the study *Characteristics and Pollution Problems of Irrigation Return Flow*, the U.S. Environmental Protection Agency explains how the use of canal water and the lack of drainage damaged ancient agricultural systems. Farmlands sat lower than canals, allowing water to flow in the direction of gravity. If water could not drain away, it evaporated and left a light salt deposit on the soil's surface. The salt residue also drew the salt lying deep beneath the soil, upward. In due course the salty soil turned toxic and could not support crop growth.[24]

The Oriental Institute of the University of Chicago website discusses the high levels of salt in southern Iraq's present-day soil. A link directs researchers to a document titled "Southern

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[23] Arthur F. Pillsbury, "The Salinity of Rivers," *Scientific American.* 245(1):54-65, 1981. http://www.sci.sdsu.edu/salton/TheSalinityofRivers.html Accessed October 12, 2013.

[24] Robert S. Kerr, *Characteristics and Pollution Problems of Irrigation Return Flow*. U.S. Department of the Interior: Federal Water Pollution Control Administration, 1969. http://nepis.epa.gov/Exe/ZyNET.exe/9101AMX0.txt?ZyActionD=ZyDocument&Client=EPA&Index=Prior%20to%201976&Docs=&Query=%28salt%29%20or%20%28salt%29%20OR%20FNAME%3D%229101AMX0.txt%22%20AND%20FNAME%3D%229101AMX0.txt%22&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX%20DATA%5C70THRU75%5CTXT%5C00000019%5C9101AMX0.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=10&ZyEntry=1. Accessed October 6, 2013.

Mesopotamian Landscape as Input for a Model on Ancient Mesopotamia Society." The document provides text and photos detailing ancient canal sites and the negative impact ancient irrigation had on the alluvial plain of southern Mesopotamia (Sumer). The author states, "Most of the soils of the alluvium have lowered agricultural potential due to high levels of salt."[25] In *The Iraqi Marshlands and the Marsh Arabs: The Ma'dan, their Culture, and the Environment* the authors confirm the long-lasting damage in present-day Iraq; "To this day salinity continues to be not only a major agricultural problem in southern Iraq but also a cause of the decreased water quality of the remaining marshes."[26]

The environmental damage caused from aqueduct canals in ancient Sumer signified a mere prelude to the harm they would cause throughout history. The salinization of soil represented a major problem for many irrigating cultures in the centuries to come. Because its land possessed adequate drainage, ancient Egypt embodied one of the few regions using extensive irrigation that did not culminate in salty, unusable soil. Later, navigation canals built to transport cargo and humans would produce different kinds of environmental problems than aqueduct canals had.

[25] Carrie Hritz & McGuire Gibson, "Southern Mesopotamian Landscape as Input for a Model on Ancient Mesopotamia Society," *Oriental Institute: University of Chicago,* (no date given), 1, 8, 9. http://oi.uchicago.edu/OI/PROJ/MASS/papers/SAA04_Hritz_Gibson_paper.pdf, Accessed on July 23, 2013.

[26] Kubba, *The Iraqi Marshlands and the Marsh Arabs: The Ma'dan, their Culture, and the Environment,* 9.

CHAPTER I:

SHORT HISTORY OF SELECTED WATER CANALS

Pre-Columbian Americas

Canal building may have begun in the New World around the same time as the Old World. Archaeologists found human-made water channels in the Andes Mountains that date back nearly 7,000 years. Like the ancient canals of the Mesopotamian river valleys, organizing and maintaining canals in the Andes Mountains transformed people's lives. Evidence shows an advanced system of government built and supported the canal systems.[27]

Millennia later the Inca and the Maya developed exceptional proficiency in water management. They accomplished extensive canal building without the use of wheels, screws, or large domesticated animals.[28] Sometime before 400 BCE the Classical Maya moved enough volumes of earth to dig a 4,000 foot drainage canal near the ancient city of Cerros. Like the Maya, the Incans built and maintained sophisticated canal systems. Inspectors and engineers performed advanced water management involving an understanding of highly complex hydraulic principles.[29]

Persia

Sometime around the eighth century BCE, Persians developed and refined the use of qanats. An ingenious and effective means of mining groundwater, qanats consisted of inclined aqueduct canals extending deep within hillsides. Although a dangerous line of work, digging

[27] Nicholas Bakalar, "Ancient Canals in Andes Reveal Early Agriculture." *National Geographic News,* (http://news.nationalgeographic.com/news/2005/12/1205_051205_peru_canals.html, 2005).

[28] Fagan, *Elixir: A History of Water and Humankind,* 248.

[29] Norman Hammond, "Mesoamerica," *Builders of the Ancient World: Marvels of Engineering* (Washington, DC: National Geographic Society, 1986), 82.

qanats grew into a specialized craft. Qanat diggers, also called mughanis, determined where to excavate by studying the terrain, the slope, and the vegetation of a hill. They would then dig a vertical shaft to establish the existence and deepness of the water table. At the top of the shaft sat a windlass (figure 7). Equipped with a bucket and rope, the windlass raised excess soil (also called spoil). Workers utilized the spoil by forming a raised mound around the perimeter of the shaft opening. The circular mound served to protect the opening from water and soil runoff.[30]

Upon establishing that an aquifer sat in an impermeable stratum of rock and could produce a constant flow, the trial shaft would then serve as the mother shaft of the qanat. Mughanis then dug more vertical shafts in alignment, again using windlasses. While progressing down the hill, each vertical shaft grew shorter in height. After digging a series of vertical shafts, mughanis then dug the horizontal tunnel (qanat) that would eventually carry the water (figure 8). Starting where water would ultimately emerge from the ground, mughanis dug toward each of the aligned vertical shafts, using windlasses along the way. Mughanis often died from tunnel cave-ins or from drowning upon reaching the mother spring. Once completed, qanat users diverted water into external aqueduct canals for irrigation or human consumption.[31]

China

The land of China contains many rivers, but few join each other naturally. The ancient Chinese developed technology that changed their rivers into a vast transportation network.[32] In about 600 BCE the Chinese completed the Grand Canal, which connected more than a thousand

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[30] Fagan, *Elixir: A History of Water and Humankind*, 141; 142.
[31] Ibid., 143.
[32] William H. McNeill, *The Pursuit of Power: Technology, Armed Force, and Society Since A.D. 1000* (Chicago: Basil Blackwell Publisher Limited, 1982), 31.

miles of waterways throughout eastern China. It still holds status as one of the world's longest human-made waterways.[33]

Building the Grand Canal challenged its engineers with immense problems. To overcome upward elevation, the Chinese invented the summit canal. Summit canals contain elaborate systems of sluice gates, ramped channels, and locks, allowing water vessels to travel uphill. To compensate for short supplies of water in the higher areas, the Chinese built feeder canals to bring water from faraway rivers and streams.[34]

Many of China's most highly developed cities sprang up along the Grand Canal, most notably the cities of K'ai-feng in the north and Hang-chou in the south. Around 400 BCE the Chinese built the Wild Geese Canal to transport military units to the Yellow River. In 221 BCE the building of the Magic Canal made water transport possible between northern and southern China.[35]

Roman Empire

Engineers of ancient Rome built two types of canals. As a highly military state they built navigation canals to transport soldiers and supplies. As a culture obsessed with cleanliness, Romans also built the largest aqueduct systems in the ancient world. Roman aqueduct canals supplied fresh water to public baths, public fountains, and to the superb public sewer systems of Roman cities. Some of the aqueduct canals constructed 2,000 years ago still provide fresh drinking water to the citizens of modern-day Rome.

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[33] Ann Nottingham Kelsall, "China," *Builders of the Ancient World: Marvels of Engineering* (Washington, DC: National Geographic Society, 1986).

[34] Ibid.

[35] McNeill, *The Pursuit of Power: Technology, Armed Force, and Society Since A.D. 1000,* 30.

At its peak, 11 main aqueduct canals flowed into Rome (figure 9). Building them required copious amounts of money, materials, and slave power. To determine the quality of water, engineers considered the physical attributes of nearby inhabitants. If local people possessed strong bodies and clear skin, engineers favored those areas for building aqueducts. Mountain springs served as the most common source for Roman aqueduct canals. Capturing water from springs required the use of catch basins connected to feeder tunnels. From there the water entered an aqueduct conduit. When a river served as the source, Romans built dams and reservoirs.[36]

Whatever the source, Roman aqueducts depended solely on gravity to deliver water to their urban destinations. Sources located in hilly regions obviously worked best. Canadian classicist Dr. A. Trevor Hodge wrote *Roman Aqueducts and Water Supply*. Considered by some the definitive account of Rome's aqueduct and water systems, Hodge presented thorough, detailed facts on the gradients of aqueducts canals. Highly skilled Roman surveyors made sure gradients ran at an acceptable pace. If aqueduct canals ran too steeply, erosion occurred. If they ran too shallow, water stagnated ruining the fresh quality.[37]

To traverse dry valleys and river valleys, engineers erected aqueduct bridges (figure 10). Also called viaducts, these structures consisted of a series of short spans supported on arches. To overcome hills, engineers built tunnels. Pressurized pipes called inverted siphons later came into use. Although rare in Rome itself, Roman provinces such as Gaul had numerous inverted siphons added to aqueduct canals. To facilitate ongoing maintenance, engineers built vertical manholes near conduits. Once water reached the city it poured into a distribution tank called a castellum. From the castellum (figure 11), water branched into smaller conduits. Each conduit led to smaller

[36] A. Trevor Hodge, *Roman Aqueducts & Water Supply,* (London: Gerald Duckworth & Co. Ltd., 1992) 79.
[37] Ibid., 2.

castella. The water branched out again into channels that supplied water to fountains, baths, and wealthy homes. The final dispersal of water occurred as it passed into drains and sewers.[38]

Citizens of Roman metropolises experienced great pride for their water systems. In 97 CE authorities appointed Sextus Julius Frontinus (35-104 CE) as water commissioner of Rome. A trusted public servant and champion of reform, Frontinus wrote several technical treatises including *De Aqueducta Urbis Romae (Aqueducts of Rome).* In this essay Frontinus described in detail the names of Rome's 11 main aqueduct canals, the engineers who built them, the sources of water for each aqueduct, and the aqueducts' precise courses.[39]

Frontinus researched laws, techniques, and the social importance of the aqueduct canals. He pointed out that large engineering projects usually occurred to appease religious deities or to honor powerful leaders. The steady flow of freshwater provided by aqueducts however greatly improved the lives of everyday citizens. Frontinus praised the practical value of the aqueduct canals to the public; "With such an array of indispensable structures carrying so many waters, compare if you will, the idle Pyramids or the useless, though famous works of the Greeks."[40]

The scientific writings of Roman scholar Pliny the Elder (23-79 CE) have passed down through the ages. In *Natural History*, written in 77-78 CE, Pliny includes facts about water systems, wells, and locating water sources. He too held admiration for Roman aqueduct systems. He praised Rome's ample supply of water "…houses, gardens and suburban villas, the distance the water travels, the arches which have been built up, the mountains tunneled, …nothing more marvelous has ever existed in the whole world."[41]

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[38] Ibid., 12; 147; 174.

[39] Fagan, *Elixir: A History of Water and Humankind*, 177.

[40] Sextus Julius Frontinus, *De Aqueducta Urbis Romae,* Cambridge Classical Texts and Commentaries (2004). http://site.ebrary.com/lib/apus/docDetail.action?docID=10130463. Accessed August 30, 2013.

[41] Pliny the Elder, *Natural History*, (Cambridge: Harvard University Press, 1938) 36.123.

Middle Ages

The medieval era saw the development of important water technology. Staunches, also called flood or tidal gates now came into use. Initially used by the Chinese in the first century BCE, staunches later helped control water levels in Europe. Watermills, flash locks, and pound locks also developed in medieval Europe.[42] A few notable canal projects from the early Middle Ages included the Karlsgraben Canal, also called the Fossa Carolina. Built on the orders of Charlemagne in 793 CE, the Karlsgraben Canal connected the Danube water basin to the Rhine water basin. In about 1100 CE, northern Italians revived several aqueduct canals and transport canals originally built by ancient Romans.[43]

Connecting England's River Trent at Torksey to Lincoln, the Roman-built Fossdyke Canal underwent restoration during the reign of Henry I (1100-1135 CE). Because of heavy silt build-up, reconstruction of the Fossdyke Canal occurred on several more occasions over the next 250 years.[44] During the Hundred Years War, England's Edward III (1327-1377 CE) and his son the Black Prince held several regions in France, including an area near the River Aa. During that time the English invaders built a towpath used to transport goods to Cahor. In 1365 CE, Edward III also appointed officials to again oversee the cleaning and repair of the ancient Fosskyke Canal in England.[45]

The upsurge of medieval Christian monasteries and abbeys triggered much canal building in Europe. In England alone the construction of at least 15 monastic canals took place between

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[42] Charles Hadfield, *World Canals: Inland Navigation Past and Present* (New York: Facts on File, 1986), 30; 26.

[43] John Blair, "Waterways and Canal-Building in Medieval England," *Medieval History and Archaeology,* (New York: Oxford University Press, 2007), 2.

[44] Ibid.

[45] P.J.G Ransom, *The Archaeology of Canals,* (Tadworth, England: World's Work, 1979), 10; 25.

1100 and 1300 CE.[46] In France a twelfth century monk described the many uses of canal water flowing into his abbey. He noted how "hardworking brethren" had dug the channel allowing water from the River Aube to flow into the monks' facility. Canal water would first hit the millstones to grind grains. Next, monks used the same flow for drinking water. Next, the canal water traveled into the tanner shops. Finally, leftover water carried human waste away from the compound.[47]

In the year 1215, Clause 41 of the Magna Carta declared free use of water travel in England. Parliament confirmed the charter at least 44 times in the next 200 years.[48] Traveling by water without the burden of paying tolls proved beneficial to England's economy. Yet much inland water travel remained for monastic purposes. In 2008 archaeologists discovered an intricate medieval canal system in Lincolnshire, England. Monks had ordered the canals built to transport large amounts of stone to nearby monastic complexes. The canal system in Lincolnshire represented a very well-built edifice. It remained unsurpassed in engineering skill for many centuries.[49]

Erie Canal

With the advent of the Industrial Age, navigation canals took on new importance. Several factors altered transportation. The large number of commuters needing interior passage signified a major conversion in transportation. In addition, the birth of steam power impacted the conveyance of cargo from one place to another. Moreover, freight laden with coal, timber, and

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[46] Douglas Caffyn, "Boats on our Rivers Again," (*Caffyn on Rivers,* 2011), 6. http://www.caffynonrivers.co.uk/_resources/cms/pdf/boats_on_our_rivers_again.pdf. Accessed on August 17, 2013.

[47] Fagan, *Elixir: A History of Water and Humankind*, 310.

[48] The Magna Carta, "Clause 41," (*Treasures in Full: The British Library Board, 1215).* http://www.bl.uk/treasures/magnacarta/translation/mc_trans.html. Accessed August 27, 2013.

[49] Erik Kwakkel, "Medieval Canals Spotted from Air," (*Alembic: University of Victoria* , 2008), 3. http://web.uvic.ca/medieval/downloads/alembic1-3.pdf. Accessed August 10, 2013.

other heavy materials did not move easily across land. Thus began the era of constructing large shipping canals.

The Erie Canal in New York State contributed to the United States' rise during the Industrial Revolution. It initially began as the brainchild of American engineer and inventor Robert Fulton. Elkanah Watson who served as an aide to Benjamin Franklin also contributed to initial suggestions on the project. Yet a shrewd, hardworking New York politician named DeWitt Clinton drove the "Big Ditch" project to realization. Construction of the Erie Canal began in 1817 and ended in 1825. More than 360 miles long, 40 feet wide, and four feet deep, the Erie Canal ranked as the longest canal in the world at that time. It still remains the longest in the United States. Its locks' system lifted barges to an elevation of more than 600 feet over the Appalachian Mountains.[50]

The Erie Canal provided an important commerce route for the new nation. It linked all five of the Great Lakes to the Hudson River which flowed into Manhattan's waterfront. Large amounts of cargo coming from the interior of the United States now traveled to the waterfronts of the already busy trade harbor of New York City. Consequently, New York City developed into a highly important world seaport and commerce center. Soon it grew into the largest and richest city in the United States.[51]

Boats traveling on the Erie Canal could only carry 30 ton cargos. Thus, starting in 1836 and lasting until 1862, new construction formed a bigger canal. The new canal allowed ships to carry 250 tons of cargo at a time. By then, instead of mules pulling the hefty loads, steam-powered tugboats pulled barges. Because of the increasing sizes of modern-day ships, by 1994

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[50] Solomon, *Water: The Epic Struggle for Wealth, Power, and Civilization*, 290.
[51] Ibid., 291.

the Erie Canal could no longer accommodate large cargo transports. Today the Erie Canal provides mostly recreational advantages.[52]

Suez Canal

Much of the industrial world took notice of the amazing economic benefits of the Erie Canal. Beginning in 1859, construction began on the Suez Canal. Like its ancient counterpart, the modern-day Suez Canal linked the Mediterranean Sea to the Red Sea. French diplomat Ferdinand de Lesseps stood as the mastermind behind the building of the Suez Canal.[53] Taking 11 years to complete, about one and a half million workers, mostly Egyptians, worked at constructing the canal. Up to 125,000 of the workers died, many from contracting cholera. Because the land it runs across stands at sea level, the 118 miles long Suez Canal does not contain locks. Construction of the Suez Canal shortened the sea route from Great Britain to India by about 6,000 miles.[54]

[52] Ibid., 295
[53] Ibid., 235.
[54] Ibid.

CHAPTER II

PANAMA CANAL

The Panama Canal connects the Atlantic Ocean to the Pacific Ocean across a narrow, tropical isthmus between the North and South American continents. The Panama Canal stretches only 50 miles; less than half the length of the Suez Canal (118 miles) and much shorter than the Erie Canal (363 miles). Yet due to the topography, climate, and many other factors, the Panama Canal proved far more difficult to build than previous canals.[55]

Early Plans

For several hundred years people held interest in creating a water passage across the Central American Isthmus. In the early sixteenth century Vasco de Balboa, one of the first Europeans to explore the New World, discovered that just a narrow sliver of land divided the two great oceans from each other (figure 12). Twenty years later Spanish monarch Charles I commanded an inquiry into building a canal. His surveyors suggested a site near the Chagres River, the largest body of freshwater on the tropical land bridge. Although the project never developed past the investigation phase, the surveyors' proposed route followed what would later represent the modern-day route of the Panama Canal.[56]

Determining where to build a canal and what type of canal to build embodied two long-standing questions. In the early nineteenth century German naturalist Alexander von Humboldt explored the Central American Isthmus. He suggested several canal routes including one through

[55] Henry Petroski, *Remaking the World: Adventures in Engineering* (New York, NY: Alfred A. Knopf, Inc., 1997) 168.

[56] Stephan Gollasch, Bella Galil, and Andrew N. Cohen, *Bridging Divides: Maritime Canals As Invasion Corridors*, (Dordrecht, The Netherlands: Springer, 2006), 96.

Nicaragua. In 1848 the Chagres River route came to the forefront again. That year miners had discovered gold in California. Hundreds of men from North America's eastern seaboard traveled to the Caribbean-Atlantic side of the isthmus. They walked across the tropical land strip to join ships headed for California on the Pacific side. The route forged by the gold-seekers roughly followed the route of the Panama Railroad completed a few years later by private financiers. Stretching 48 miles long and transporting passengers on a three hour trip, the Panama Railroad remained the isthmus' primary mode of transportation for half a century.[57]

In 1852 while serving as a U.S. Army officer, Ulysses S. Grant led a military taskforce across the Central American Isthmus. The group of several hundred people enroute to California included soldiers and their families. Many of the participants died from cholera. Later while serving as president, Grant sent several expeditions to analyze possible canal sites. Officials investigated potential routes through the Darien region of Panama, the Chagres River of Panama, a route alongside the Panama Railroad, a route through Lake Nicaragua, and even a route across southern Mexico. The final report written by the U.S. Interoceanic Canal Commission in 1876 recommended Lake Nicaragua as the favored route.[58]

French Attempt

A year earlier Count Ferdinand de Lesseps (figure 13) proclaimed his desire to build a canal through the Central American Isthmus. A few years previously de Lesseps had successfully led construction of the modern Suez Canal in Egypt. Now the "Hero of Suez" wanted a second

[57] Ibid., 97.
[58] Ibid., 98.

act. De Lesseps created an organization to conduct studies, raise money, and lobby the French government to support a Panamanian canal project.[59]

De Lessep's company sent Navy Lieutenant Lucien Napoleon Bonaparte Wyse, an engineer and great nephew of the deceased emperor, to explore the Central American Isthmus. Because Wyse's initial proposal involved building a summit canal with locks, de Lesseps rejected it. Wyse then recommended a route that ran adjacent to the Panama Railroad. This plan included digging an eight-kilometers-long tunnel through the Culebra Pass (formerly the Gaillard Pass) on the Continental Divide. In all, the French considered 14 potential sites for the canal.[60]

De Lessep continued to push strongly for a sea-level canal. Yet an engineer named Baron Godin de Lepinay who had successfully built a railroad in Mexico proclaimed de Lessep's sea-level proposal as doomed. Instead, de Lepinay recommended the Chagres River route. Surveyors hired by Spain's Charles I had proposed the same course nearly four centuries earlier. De Lepinay's proposal included building dams on the Gatun and Chagres rivers which would create a large artificial lake. The resulting reservoir would serve as the primary waterway of the canal. Ships would negotiate up a series of locks, traverse the large reservoir, then travel down a series of locks on the other side. De Lepinay's design contained very similar elements to the design the United States would later successfully build.[61]

De Lessep on the other hand continued to advocate a canal at sea-level, parallel to the Panama Railroad. He had successfully achieved a sea-level canal in Egypt and believed he could also build one at Panama. De Lessep's stubbornness prevented him from recognizing that the vastly different topographies of the two regions required vastly different types of canals.

[59] Ibid.
[60] Ibid., 98; 99.
[61] Ibid., 99.

Nevertheless, in 1879 France's government approved de Lessep's proposal for the sea-level route. In addition to France's financial contribution, de Lessep raised private capital in other countries including the United States and England.

In 1880 under the leadership of Ferdinand de Lessep, not an engineer but a diplomat by trade, the French officially began construction on a Panamanian, sea-level canal. De Lessep hired one of his sons, Charles, to directly supervise much of the work. Almost immediately the behemoth project underwent tribulations. Thousands of workers died from tropical diseases, especially malaria and yellow fever. Swamps and jungles abounded with crocodiles, bats, and poisonous snakes. The Chagres River, one of the most volatile rivers on earth, frequently flooded the region. Planners had grossly miscalculated the amount of spoil they would need to remove for a sea-level canal. Landslides buried workers, destroyed equipment, and frequently halted production. Costly yet ineffective machinery lay in heaps where workers had abandoned them (figure 14). In addition to natural problems, widespread corruption afflicted the project.[62]

In 1888 after more than eight years of misery, de Lessep finally discarded the sea-level route. He now supported building a summit canal with locks. Yet the change of plans came too late. Financial backers had lost faith and refused to bestow more money on the floundering enterprise. By late 1888 the project went bankrupt with work halting the following year. The French government indicted the de Lesseps and other participants on charges of fraud, corruption, and bribery. Most of the charges stemmed from the initial launching of the project when planners had bribed French officials to back their sea-level design. Although the court

[62] Julie Greene, *The Canal Builders: Making America's Empire at the Panama Canal* (New York: Penguin Press, 2009), 2; 26.

found both men guilty, the sickly, elder Ferdinand de Lesseps did not serve time in prison. His son Charles de Lesseps served a year in prison.[63]

After the de Lessep debacle, Lucien Napoleon Bonaparte Wyse reentered the picture. Determined to see the project to completion Wyse restructured the Panama project with new plans for a summit canal with locks. Unfortunately, neither the French government nor private backers entertained notions of funding the project again. For most people the name Panama now symbolized danger, corruption, and death. Yet in 1899, canal directors from France approached the U.S. Government.[64]

American Endeavor

During the prior three decades the youthful United States had ascended on the world stage as an impressive industrial power. In 1898 the young nation rose further up in status when it flexed its military muscle and won several territories during the Spanish-American War. On its Atlantic side the United States now controlled Puerto Rico and Cuba. On its Pacific side the United States gained the Far East lands of Guam and the Philippines. Earlier the United States had annexed the Territory of Hawaii. For both military and commercial purposes, building a canal through the tropical land bridge seemed more important than ever. President William McKinley began a major study of possible canal routes on the Central American Isthmus. The route on Lake Nicaragua again came to the forefront as a preferred site.[65]

Before his assassination in 1901 President McKinley had strongly supported building a Central American canal. Yet McKinley's successor, Theodore Roosevelt, a highly astute

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[63] Gollasch, et.al., *Bridging Divides: Maritime Canals As Invasion Corridors*, 100.

[64] "French Canal Construction," *A History of the Panama Canal: French and American Construction Efforts*, Panama Canal Authority. http://www.pancanal.com/eng/history/history/. Accessed November 7, 2013.

[65] Gollasch, et.al., *Bridging Divides: Maritime Canals As Invasion Corridors*,100; 102.

politician, would rise as the fierce champion of the canal project. Perhaps more than any other American president, Roosevelt advocated the spread of American imperialism and authority. He envisioned the United States transforming into a mighty sea power. The palindrome “A man, a plan, a canal – Panama” refers to President Roosevelt’s efforts during the initial years of the formidable task.[66]

The U.S. Congress continued to debate over the location of the canal. Many, including the presidentially appointed Isthmian Canal Commission continued to favor a route through Lake Nicaragua. Yet the unsuccessful French canal builders still yearned to recoup their financial losses. They pressed to sell their Panamanian property rights and equipment to the United States. The French even reduced their price from $109 million to $40 million. Several natural events tipped the scales in favor of buying the French’s Panamanian route. In May 1902, Mount Pelee, a volcano in the eastern Caribbean Sea, erupted killing thousands. Six days afterward a volcano in Nicaragua erupted as did a volcano further east at St. Vincent. Eager to steer clear of the volcanic mayhem, Congress soon passed a bill apportioning funds for the Panama route.[67]

The nation of Colombia held control over the Panamanian Isthmus. Because Colombia’s constitution forbade allocating land to foreign nations, they rejected the United States’ canal treaty. Yet a rebellious faction had long smoldered in the Panama region. In 1903 Panamanians declared the isthmus the new Republic of Panama. The event provoked the Colombian Government to send troops. The U.S. Government sent money to Colombian soldiers bribing them to return home. Thus, the revolution proved short-lived and bloodless with Panama’s nationalists deemed the winners. The world now recognized the Republic of Panama as a

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[66] Ibid., 102.
[67] Ibid., 103; 104.

sovereign nation. Soon after, the new country signed a canal treaty with the United States of America.[68]

In the official 1903 treaty titled *Convention with Panama for the Construction of the Panama Canal,* Panama granted the United States a ribbon of land 10-miles wide along a 50-mile long strip called the Canal Zone. The agreement discussed property rights, military matters, and annual payments. Articles II and IV of the treaty described the rights of the United States to utilize the natural bodies of water for use in the construction and maintenance of the canal. The treaty also allocated responsibility to the United States for sanitation, sewage, and water management in the urban regions of Panama City and Colon. The wording of the treaty recognized the need for the United States to conduct the project with reasonable prudence.[69]

Beginning in 1904 under the leadership of railroad engineer John Wallace, the United States launched the Panama Canal project. The following year Wallace resigned. Roosevelt and the Isthmian Canal Commission replaced him with another railroad engineer named John Stevens. Like the French, the Americans set out to build a sea-level canal. Like the French, the Americans underwent enormous difficulties. Located in a tropical rainforest climate, the Panama region receives an average of over 100 inches of precipitation a year.[70] In addition to rain, disease, and excessive heat, the Americans faced daunting problems of massive spoil removal.

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[68] Ibid., 104.

[69] "Convention with Panama for the Construction of the Panama Canal," *Convention with Panama for the Construction of the Panama Canal,* (January 9, 2009): 1. http://web.ebscohost.com.ezproxy1.apus.edu/ehost/detail?vid=4&sid=36b9f4c8-f764-4145-a3a0-0fa4146d8f39%40sessionmgr13&hid=18&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=aph&AN=21212249. Accessed July 28, 2013

[70] Arthur F. Pabst, *Some History and Hydrology of the Panama Canal,* U.S. Army Corps of Engineers: Institute for Water Resources, 2000. http://www.hec.usace.army.mil/publications/TechnicalPapers/TP-159.pdf. Accessed November 8, 2013.

The Americans nevertheless held a big advantage over the French – the Americans had the luxury of learning from the ordeals of the French.[71]

In 1904 the United States appointed Colonel William Gorgas as Chief Sanitary Officer for the Panamanian project. Gorgas understood the importance of finding the sources of yellow fever and malaria. Staggering death rates from these sicknesses had devastated the French workforce. Frightening symptoms included seizures, jaundice, bloody vomit, and kidney failure. Patients who survived yellow fever attained immunity to the virus but those with malaria could acquire the parasite again and again. Some individuals suspected mosquitoes as the culprit for both diseases. Most people however, including many in the medical field, still believed yellow fever and malaria came from miasma, mists rising from swamps. Some people even believed the illnesses arose from sinful lifestyles.[72]

With the full support of Chief Engineer Stevens, Chief Sanitary Officer Gorgas implemented a progressive medical campaign. Through his program Gorgas demonstrated that specific types of mosquitoes transmitted both yellow fever and malaria to humans. In an effort to reduce the disease-carrying insects, canal workers poured crude oil onto ponds, streams, and swamps. They sprayed petroleum in water containers in people's homes, on roadside pools, and in drains. The crude oil hindered female mosquitoes from laying eggs and destroyed any larvae already in the water.[73]

Gorgas' eradication crusade saved thousands of lives. Using quarantine and sanitation procedures, he also reduced cases of tuberculosis, bubonic plague, and pneumonia, diseases that took nearly as many lives as yellow fever and malaria had. During America's 10 years of

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[71] Greene, *The Canal Builders: Making America's Empire at the Panama Canal*, 26.
[72] Gollasch, et.al., *Bridging Divides: Maritime Canals As Invasion Corridors*, 105.
[73] Greene, *The Canal Builders: Making America's Empire at the Panama Canal*, 39; 40.

building the Panama Canal, 5,609 deaths occurred from illnesses and mishaps. The American project's death rate represented only one-fifth the total deaths of the French's eight year endeavor.[74]

Thousands of workers from Central America, North America, Europe, and the West Indies arrived at the Canal Zone. At times however, mostly due to fear of diseases, the project suffered from a severe lack of workers. At its peak year in 1913 nearly 40,000 workers labored on the United States' project. In general, officials hired white people to perform skilled labor positions including blacksmiths, carpenters, craftsmen, and drill operators. In contrast, officials typically hired colored people, such as African Americans and Latinos, to perform unskilled labor positions (figure 15). These positions included ditch diggers and dangerous positions such as dynamite detonators. Supervisors paid skilled workers in gold and unskilled workers in silver. Sadly, a segregated social system arose. Signs hanging from shop windows stated "Gold Only" and "Silver Only."[75]

In addition to building the canal, project engineers erected workers' houses, medical clinics, churches, and recreation centers. Structures providing support services such as post offices, police stations, fire stations, and courthouses sprang up. Warehouses, administrative buildings, and repair facilities also represented crucial aspects of the project. Further into the project American engineers built a hydroelectric dam at Gatun Lake. The dam provided both electrical power and fresh drinking water.[76]

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[74] Ibid., 106.

[75] Ibid., 63; 66.

[76] "Sanitation and Infrastructure," *Army Engineers and the Building of the Panama Canal, 1907-1914.* No date given. http://www.armyengineer.com/history/panama/projects/Sanitation/Sanitation.html. Accessed November 8, 2013.

The Panama Railroad proved one of the most important features of the American's Panama Canal project. Under Stevens' skillful leadership, he transformed the rail system into a logistical marvel. Like a large conveyer belt, train cars carried away massive amounts of spoil from work sites then hurriedly rolled back to take away more. The railroad worked closely and efficiently with other forms of large machinery (figure 16). The Bucyrus Company in Milwaukee, Wisconsin supplied behemoth steam shovels for the project. Long beams mounted on flat cars lifted and moved rail tracks without having to take them apart. Stevens also employed open-side flat cars fitted with plows to reduce time.[77]

In 1906 during the height of Panama's wet season, President Theodore Roosevelt, his wife Edith, and several dignitaries visited the Canal Zone. The trip represented the first time an American president had left United States' boundaries. A master of the emerging mass media, Roosevelt enjoyed both newsreel and still-photo opportunities. He posed with large equipment including a now-famous photo of him sitting at the helm of a Bucyrus steam shovel (figure 17). Roosevelt toured workers' living quarters, visited hospitals, inspected urban regions, and studied natural areas. He spoke with skilled laborers, unskilled laborers, and gave inspiring speeches. Roosevelt seemed to marvel over the project that he himself had worked so hard to launch. His trip to the Canal Zone improved the public's perception of the project, which had waned in recent months.[78]

In 1907, citing personal reasons, Chief Engineer John Stevens resigned from the project. Roosevelt replaced Stevens with George Washington Goethals of the U.S. Army Corps of Engineers. As civilians, Wallace and Stevens could resign at will. Hiring a military officer such

[77] Gollasch, et.al., *Bridging Divides: Maritime Canals As Invasion Corridors*, 107.
[78] Greene, *The Canal Builders: Making America's Empire at the Panama Canal*, 199-203.

as Goethals meant Roosevelt would not have to replace him. Goethals remained until the completion of the canal project. Afterward he served as Governor of the Canal Zone.[79]

Several months before Stevens resigned he had traveled to Washington, D.C. to meet with President Roosevelt. Up to this point the United States' canal design reflected a design similar to the design the French had struggled to build twenty years earlier – a canal at sea-level. Stevens convinced Roosevelt that because of the severe instability of the Chagres River, building a sea-level canal would prove disastrous. In 1906, Roosevelt, the Isthmian Canal Commission, and the U.S. Congress agreed to discard the sea-level canal in favor of building a summit canal.[80]

The new route, a path quite similar to the Spanish surveyors' proposed route 400 years earlier, meant building a large dam (figure 18) on the Chagres River. The waters impounded at the dam would create Gatun Lake, at that time the largest human-made lake on earth. Traveling across Gatun Lake would represent nearly half the route a ship would take while navigating the canal. The summit canal would utilize several gigantic locks for ships to scale up and then down the canal path. The path of a ship approaching from the Atlantic-Caribbean side would take the following route: Originate at Limon Bay; negotiate up the Gatun Locks; traverse Gatun Lake; pass the Culebra Cut; negotiate down the Pedro Miguel Lock and the two Miraflores Locks; and finally reach the Pacific Ocean (figure 19). The cities of Colon and Limon Bay represented the main urban areas on the Atlantic side, whereas Panama City represented the primary urban center on the Pacific side.[81]

Because the design of the canal had changed from a sea-level canal to a summit canal, a flurry of reorganization took place. Since much of the railroad would soon lay underwater,

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[79] Gollasch, et.al., *Bridging Divides: Maritime Canals As Invasion Corridors,* 108.
[80] Ibid., 107.
[81] Greene, *The Canal Builders: Making America's Empire at the Panama Canal*, 55; 56.

workers had to relocate railroad tracks. Engineers designed a hydroelectric facility at Gatun Dam, the largest dam in the world at the time, to provide power for the project. They designed the massive locks to identical dimensions and built them in pairs to accommodate traffic flow from both directions. During the four years of constructing the locks and dam, five million bags and barrels of concrete arrived. Workers mixed concrete onsite in colossal six ton buckets. The enormous locks (figure 20), each as deep as a ten story building, represented the only major portion of the project built by a private contractor.[82]

The new canal design reduced the magnitude of work at the Culebra Cut, the highest point of the project. Nevertheless, located on a steep mountain route on the Continental Divide, the Culebra Cut represented one of the greatest challenges of the project. Stretching nearly nine miles long, workers loosened millions of cubic yards of rock and earth. They drilled holes into the rock, filled the holes with dynamite, then took shelter. Along with rocks, soil, and dust flying into the air, human body parts sometimes flew. Few safety guidelines existed, which created highly dangerous conditions for workers.[83]

Work at the Culebra Cut epitomized one of the noisiest sections of the Canal Zone. On any given day workers heard repeated dynamite explosions, hundreds of drills rumbling, dozens of steam shovels working, and train whistles howling. The injurious noise accompanied temperatures exceeding 120 degrees Fahrenheit, and at certain times of the year, continuous rain. The perpetual downpour loosened soil, creating massive mudslides (figure 21). Workers and engineers toiled to stabilize the embankments. Despite the tremendous hardships, work carried on.[84]

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[82] Greene, *The Canal Builders: Making America's Empire at the Panama Canal,* 54-56.
[83] Ibid., 45.
[84] Ibid., 44.

In May of 1913 steam shovel operators from both sides of the Culebra Cut broke the earthen barrier. On October 10 of that year, under budget and ahead of schedule, waters from both sides of the project met. The following year on August 15, 1914, just two weeks after the start of WWI, a simple towboat represented the first watercraft to traverse the entire Panama Canal.[85] Serving as one of the most important human-made waterways in history, the canal lopped off 7,800 miles of sea voyage for ships traveling from New York City to San Francisco.

Panama Canal and the Environment

Some referred to the Panama Canal as, "…an unparalleled engineering triumph."[86] Others referred to it as, "The greatest liberty Man has ever taken with Nature."[87] During its construction in the early twentieth century, few people considered issues of environmental damage. Thus, the original treaty did not discuss the fragile ecosystem of the Panama Isthmus nor the impact the canal would potentially have on the tropical biome. Environmentalists today know that in the process of building the canal great damage did indeed occur. Excavators leveled mountains, impounded rivers, and covered wetlands with crude oil. To cause damage of this kind to any ecosystem would mean misery to the natural realm. To a region that held some of the richest wildlife diversity in the world, it meant near catastrophe. In some instances entire species ceased to exist. In his book *Insatiable Appetite: The United States and the Ecological Degradation of the Tropical World*, Dr. Richard P. Tucker writes "They [the United States]

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[85] Ibid.
[86] Petroski, *Remaking the World: Adventures in Engineering,* 168.
[87] Ibid.

transformed an entire region of tropical Panama to meet the requirements of a global network of trade and security …"[88]

Because attempts to build a canal at sea-level through the Panama Isthmus had failed, engineers built the "bridge of water," over the rugged terrain of the Continental Divide. Impounding the Chagres River and Gatun River created Gatun Lake, the primary waterway of the Panama Canal. This reservoir required copious amounts of water. It submerged 425 square kilometers of tropical plants and animals under the lake. It turned hills into islands and destroyed land-dwelling life forms below the water level. Building the Panama Canal did more than disturb the delicate jungle ecosystem – it forever changed the natural order.[89]

For hundreds of millions of years South America and North America existed apart from each other. About three million years ago the two landmasses permanently merged, which created the Central American Isthmus. Geologists believe the merging actually took place over long periods of time with gaps opening and closing several times. For land-dwelling life forms, the back-and-forth rejoining created extraordinary biodiversity. Plants and animals from the two continents blended and evolved giving rise to thousands of unique species.[90]

On the other hand, the eventual formation of the land bridge kept marine creatures in the Atlantic Ocean and Pacific Ocean perpetually separate. When the isthmus permanently forged, saltwater biota from each side of the isthmus evolved quite differently from each other. Cutting an artificial channel through the land bridge reintroduced long-separated species, which caused many environmental problems.[91] In *Bridging Divides: Maritime Canals as Invasion Corridors*,

[88] R. P. Tucker, *Insatiable Appetite: The United States and the Ecological Degradation of the Tropical World*, (Berkeley, CA: University of California Press, 2000) 418. http://site.ebrary.com/lib/apus/docDetail.action?docID=10054460 Accessed September 8, 2013.

[89] Gollash, et.al., *Bridging Divides: Maritime Canals As Invasion Corridors*, 127.

[90] Ibid., 91.

[91] Ibid., 91; 92; 95.

the authors explore the biological conditions of aquatic animals near each side of the Panama Canal. Their findings point to the canal as creating a major invasion passageway for harmful biota. They argue, "The introduction of alien species proved to be one of the most profound and damaging anthropogenic deeds – involving both ecological and economic costs."[92]

Ships traversing the Panama Canal come from all around the world. Their hulls, rudders, and ballast tanks contain living aquatic organisms from exotic territories. Although data remains inconclusive, researchers believe biota transferred by ships has caused a shift in the composition and abundance of species in the Panama region. Furthermore, the back and forth transfer of saltwater and freshwater in the canal creates great stress on aquatic life forms.[93]

Expansion of the Panama Canal

In 1999, after a lengthy 22-year process, the United States officially handed control of the Panama Canal to the nation of Panama. In April 2006 the Panama Canal Authority officially proposed a massive building project to enlarge the existing Panama Canal (figure 22). The project, now called the Panama Canal Expansion Program, aimed to double the canal's current shipping capacity by constructing a third set of locks. Currently, large ships navigating closely from opposite directions of the Culebra Cut cannot pass through safely. Panamax, a term used by canal authorities to describe size restrictions for the canal, has influenced the designs of large ships throughout the world. Post-Panamax or New Panamax represents larger-sized ships potentially traversing through the new, larger locks. Cost estimates for the project stood at U.S.

[92] Ibid., xiii.
[93] Ibid., 125.

$5.25 billion.[94] Through a graduated toll system, ships utilizing the canal would carry the responsibility of financing the entire project. Six months after the Panama Canal Authority's recommendations, the citizens of Panama overwhelmingly voted in favor of the expansion project.[95]

During the planning of the original Panama Canal, awareness of environmental issues did not strongly exist. Most people held little concern for the impact the canal would have on the Panamanian ecosystem. A century of scientific and social progress made a major difference in the way developers perceived the new project. Dr. Ricaurte Vasquez served as Chairman of the Panama Canal Authority Board of Directors. According to Dr. Vasquez, before officially recommending the expansion plan, the group reviewed and analyzed hundreds of studies and projections. Many of the preliminary studies involved the usual financial, social, and geological characteristics of the project.[96]

Fortunately, a large number of preliminary studies also addressed the environmental impact of the expansion project. The official declaration included terms such as *environmentally-safe*, *ecological risk-assessment*, *sustainability*, and *best environmental practices*.[97] The Panama Canal Authority announced plans to construct water-saving basins (figure 23) allowing the reuse of over 50 percent of transit water. Employing the use of water-saving basins eradicates the need for building invasive dams and displacing villages. Authorities also formulated a partnership

[94] "Panama Announces Canal Expansion," *Oil Spill Intelligence Report* 20, no. 18 (April 27, 2006): 1-2. http://web.ebscohost.com.ezproxy1.apus.edu/ehost/pdfviewer/pdfviewer?vid=15&sid=36b9f4c8-f764-4145-a3a0-0fa4146d8f39%40sessionmgr13&hid=18.Accessed August 2, 2013.

[95] Ricardo Ungo, et.al., "Risk Planning and Management for the Panama Canal Expansion Program," *Journal of Construction Engineering & Management* 137, no. 10 (October 2011): 762-771. http://web.ebscohost.com.ezproxy1.apus.edu/ehost/pdfviewer/pdfviewer?vid=6&sid=92e363fb-fcbf-4a1f-a6fc-dfd9cfe1866e%40sessionmgr4&hid=24 Accessed July 31, 2013.

[96] "Panama Announces Canal Expansion."

[97] Ibid.

with an organization to implement proactive steps to ensure the safe relocation of wildlife affected by the expansion project.[98]

In building the original Panama Canal, engineering, medicine, and politics had merged to realize a spectacular achievement. The United States had triumphed over the natural world in a way no entity had ever done before. At the time, most people perceived conquering nature as a positive thing, as a sign of progress. Few comprehended the consequences of damaging ecosystems. The twenty-first century has witnessed many scientific improvements in devising ecofriendly strategies. These advances can help developers build the new Panama Canal in a way that improves the quality of life for people without gravely damaging the environment.

[98] Nestor Correa, et.al., "Strengthening Partnerships for Effective Wildlife Rescue in the Panama Canal Expansion Area," *Human Dimensions of Wildlife* 13, no. 5 (September 2008): 382-384., http://web.ebscohost.com.ezproxy2.apus.edu/ehost/detail?vid=4&sid=176c6695-6aa5-4764-8e83-4931c3ec92f4%40sessionmgr111&hid=114&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=aph&AN=34506863. Accessed August 2, 2013.

CHAPTER III

COLUMBIA BASIN PROJECT

U.S. Bureau of Reclamation

In general, the western half of the continental United States receives far less precipitation than the eastern half does. Developers in the late 1800s realized the lack of water in western states meant economic growth would never equal the astounding progress of the eastern states. In an effort to balance the scales, Congress established the U.S. Bureau of Reclamation. Founded in 1902 during Theodore Roosevelt's presidency, the Bureau of Reclamation operates under the U.S. Department of the Interior. The Bureau of Reclamation "reclaims" water in 17 western states (figure 24). Reclaiming water involves projects associated with rivers, dams, irrigation, and hydroelectric power.[99]

The extremely dry climate of eastern Washington State epitomized a prime region for the Bureau of Reclamation to develop a water recovery project. In 1882 First Lieutenant Thomas William Symons had inspected eastern Washington State and its Columbia River for the U.S. Army Corps of Engineers. In his official report he stated "It is a desert pure and simple, an almost waterless, lifeless desert."[100] In the report Symons also mentioned the rich soil of the region. He concluded that building a large irrigation system would generate abundant agricultural yields in the otherwise nearly lifeless land.

Decades later the Bureau of Reclamation implemented a large irrigation network in central-eastern Washington State. Beginning at Grand Coulee Dam, the huge edifice that feeds the irrigation project, twelve colossal pumps capture and lift water from the Columbia River.

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[99] Bureau of Reclamation – About Us," *Reclamation: Managing Water in the West.* (U.S Department of the Interior, 2013). http://www.usbr.gov/main/about/. Accessed August 25, 2013.

[100] Paul C. Pitzer, *Grand Coulee: Harnessing a Dream,* (Pullman, WA: Washington State University Press, 1994), 9.

Then, in a rather complex, fascinating manner the project diverts water to designated areas via aqueduct canals. Thousands of miles of canals, siphons, tunnels, reservoirs, pumps, and drains constitute the Columbia Basin Project (figure 25). After irrigating about 650,000 acres of crops throughout the Columbia Basin, the water drains into equalizing reservoirs with some of the water returning to the Columbia River.[101]

As Symon's had predicted, the large irrigation system altered desert-like, central-eastern Washington State into an agriculturally productive region. It provides water to over 2,000 crop farms, dairy farms, and cattle ranches. Revenues from farm production equal about $630 million a year.[102] The Columbia Basin Project holds prestige as the largest water reclamation project in United States history.[103]

Columbia River

To appreciate the importance of the Columbia Basin Project, individuals must understand its water supplier – the Columbia River – and the dry terrain it flows through (figure 26). The remote, wild Columbia River holds status as the fourth largest river in North America. Beginning in the Canadian Rocky Mountains, the Columbia River weaves a powerful path to the ocean. The river begins life at 2,650 feet above sea level then rushes to the Pacific Ocean after crossing 1,250 miles. Thus, the Columbia River plunges almost twice the height in elevation as the

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[101] Lake Roosevelt," *The Story of the Columbia Basin Project*, U.S. Department of the Interior: Bureau of Reclamation, 2008. http://www.nps.gov/history/history/online_books/dams/columbia_basin/sec2.htm. Accessed August 30, 2013.

[102] John Harrison, "Columbia Basin Project" *Columbia River History,* Northwest Power and Conversation Council, 2008. http://www.nwcouncil.org/history/ColumbiaBasinProject. Accessed October 5, 2013.

[103] "Bureau of Reclamation – Columbia Basin Project," *Reclamation: Managing Water in the West.* U.S. Department of the Interior, 2013. http://www.usbr.gov/projects/Project.jsp?proj_Name=Columbia+Basin+Project. Accessed August 27, 2013.

Mississippi River does, and in about half the distance. The Columbia River's substantial drop creates an intense, formidable current.[104]

First traveling through British Columbia, the rapidly flowing river spends most of its journey surging southerly through eastern Washington State. Ultimately, the river courses to the northern edge of Oregon, serving as the border between Washington and Oregon. Upon reaching the sea the Columbia River's estuary spills water at an average annual flow rate of 260,000 cubic feet of water per second in a high water year.[105] Much further south the Colorado River serves as the largest river in the southwest United States. In a high water year it averages an annual flow rate of 22,500 cubic feet of water per second into the Gulf of California.[106] Hence, the Columbia River carries more than 10 times the amount of water than the famous Colorado River does.

As the Columbia River meanders through dry, eastern Washington State it distinctly bends along the edge of an ancient basalt plateau. The plateau sits next to a region called the Columbia Basin. Because of ancient geological occurrences, the Columbia Basin contains exceptionally fertile soil. During the latter part of its journey, the powerful Columbia River achieves a nearly impossible feat. Called the Columbia Gorge, the river cuts a deep gouge directly through the Cascade Mountains. Geologists marvel at the river's ability to carve this 80 mile long corridor through a major mountain range. The sizeable Snake River serves as the largest tributary flowing into the Columbia River. The many other tributaries flowing into the Columbia River come from British Columbia, western Montana, Idaho, Washington, Oregon, and small portions of Wyoming and Nevada. In total, the Columbia River drains an area larger

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[104] "Columbia River Facts," *Office of Columbia River*, Department of Ecology State of Washington. http://www.ecy.wa.gov/programs/wr/cwp/cwpfactmap.html. Accessed November 16, 2013.

[105] Ibid.

[106] Kenneth C. Nowak, *Stochastic Streamflow Simulation at Interdecadal Time Scales and Implication to Water Resources Management in the Colorado River Basin*, 2011. http://cadswes.colorado.edu/sites/default/files/PDF/Theses-PhD/Nowak-PhD.pdf. Accessed November 16, 2013.

than the country of France (figure 27). It pours far more fresh water into the Pacific Ocean than any other river in North or South America.[107]

Climate of Eastern Washington State

Many people perceive the State of Washington as a lush, green region with heavy annual rainfall. This view remains correct when considering Washington State on the western, more populated side of the Cascade Range. The large green cities of Seattle, Tacoma, and the state capital of Olympia help Washington State earn its nickname as the Evergreen State.

Washington State on the east side of the Cascade Mountains looks vastly different than the west. Rainclouds that form over the Pacific Ocean dump large amounts of precipitation onto the populated west side of Washington State. Yet as the rain clouds continue eastward they remain trapped in the high Cascade Mountain Range. Because of this "rain shadow," very little precipitation falls on the eastern side of Washington State (figure 28). Snow during the harsh winter months represents most of the annual precipitation on the eastern part of the state. In addition to the extreme lack of rainfall, eastern Washington State experiences exceptionally hot summers and very cold winters.

The lack of precipitation in addition to the seasonal extremes of eastern Washington State creates thousands of square miles of parched, nearly uninhabitable landscapes. Sagebrush and patches of a few other semi-arid plants appear in the bleak, dry lands (figure 29). Watching the Columbia River carry massive volumes of water through this dry region seemed almost cruel to

[107] Anthony Netboy, *The Columbia River Salmon and Steelhead Trout: Their Fight for Survival,* (Seattle: University of Washington Press, 1980), 4.

those hoping to grow crops in the fertile soil; "They [the farmers] looked at the Columbia, the largest river in the state, and they wondered how to lift its water up onto their land."[108]

Grand Coulee Dam

The idea of building a major irrigation system on the eastside of Washington State took hold in the 1910s and 1920s. Attorneys Billy Clapp and James O'Sullivan, and newspaper publisher Rufus Wood from small towns in eastern Washington State formed a group of citizens. The group envisioned a large irrigation project to water the thirsty lands of the Columbia Basin region. Water for the project would come from a large dam built at a narrow coulee on the Columbia River. The damming of the river would create a large reservoir behind it. From the reservoir, large pumps would direct water to aqueduct canals. The canals would irrigate the dry but fertile farms, giving the region a much-needed economic boost. Back at the dam the remaining water would rush through turbines, producing boundless quantities of cheap electricity. Selling the electricity would pay for the costly dam and irrigation project. Thus the two functions of Grand Coulee Dam – irrigation and hydroelectric energy – would combine to create an entity.[109]

In 1920 while campaigning for vice president, Franklin D. Roosevelt caught wind of the proposed dam and irrigation project. Soon, part of the Democratic presidential platform that year included a commitment to the development of the Columbia River. Franklin D. Roosevelt's distant cousin, the recently deceased former president Theodore Roosevelt, had also championed the cause of reclamation in the west. Franklin D. Roosevelt and presidential candidate Brian M.

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[108] Pitzer, *Grand Coulee: Harnessing a Dream*, 6.
[109] Ibid., 9; 12; 15; 16.

Cox lost the 1920 election. The administrations of the next three presidents, all Republicans, did not move forward with the Columbia River's dam and irrigation project.[110]

In 1927 however, Congress authorized the U.S. Army Corp of Engineers to study locales on the Columbia River as potential sites for a large dam. Five years later in 1932, Colonel G.R. Lukesh of the Army Corp of Engineers submitted "Columbia River and Minor Tributaries" to the 73rd U.S. Congress. The report, officially submitted as "House Document 103," recommended the building of eight dams on the Columbia River. It endorsed constructing the largest of those dams, Grand Coulee Dam, at its current location. The report also suggested a widespread irrigation plan for the Columbia Basin region. In the official report Lukesh wrote, "It would permit irrigation of large tracts of land of both sides of the river in Oregon and Washington."[111]

Despite the report, many had abandoned the idea of building Grand Coulee Dam and the Columbia Basin Project. Yet for others the dream did not die. Franklin D. Roosevelt continued to envision the project as something similar to the building of the nineteenth century Erie Canal. Born and raised at Hyde Park on the Hudson River, Roosevelt understood the economic importance the Erie Canal had on his home region. As a transport canal however, the Erie Canal served a different purpose than the Columbia Basin's aqueduct canals would. Later, in 1934 while serving as president, Roosevelt reflected on his long-time vision of developing the Columbia River. He stated, "I could not help thinking, as everyone does, of all that water running down unchecked to the sea."[112]

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[110] Ibid.

[111] G.R. Lukesh, "Columbia River and Minor Tributaries," *House Document No. 103, 73rd Congress, 1st Session (308 Reports)*. StreamNet: Fish Data for the Northwest, 1932. http://www.streamnetlibrary.org/?page_id=68. Accessed September 28, 2013.

[112] Franklin D. Roosevelt, "143 - Remarks at the Site of the Grand Coulee Dam, Washington," The American Presidency Project, August 4, 1934. http://www.presidency.ucsb.edu/ws/index.php?pid=14732#axzz2i6hSCde9. Accessed October 15, 201.

In 1933, three months after his inauguration, President Franklin D. Roosevelt approved the Grand Coulee Dam project. Work began the following year and continued for eight years (figures 30 & 31). Because of the hardships of the Great Depression, the endeavor developed into more than an irrigation and electric-producing plan. As part of Roosevelt's New Deal policies the project had expanded into a complex, socio-political enterprise. In an effort to resuscitate the economy, President Roosevelt launched a federally sponsored program called the Public Works Association. Developed to provide employment and increase spending power, the construction of Grand Coulee Dam typified one of the large-scale projects subsidized by the Public Works Association. Unemployed workers from around the nation poured into sparsely populated eastern Washington State. By 1934, roughly 7,000 men crowded into the tiny town of Grand Coulee, Washington along with an unknown number of women.[113]

In 1934 the Columbia River signified the largest, most powerful river humans had ever attempted to dam. Once finished the massive dam would stretch almost a mile wide. In height it would rise more than 500 feet. Cofferdams would reroute the river in intervals while construction of the main dam took place. Concrete work would represent a painstaking process. Poured slowly into 50 square foot blocks, workers would then have to constantly level the wet concrete before it dried. In some places concrete would sink into the bedrock 200 feet below the surface of the river.[114]

Building the large hydroelectric components would prove challenging as well. The weight of the rushing river building up behind the dam would create potential energy. Water would then surge into large funnels called penstocks. Penstocks would force water at high speeds

[113] Pitzer, *Grand Coulee: Harnessing a Dream*, 181-192.
[114] Ibid., 136; 138.

through turbines encased in two powerhouses at the foot of the dam (in 1974 the Bureau built a third powerhouse). The force of water would spin the turbine blades causing the shaft to spin. The spinning shaft would create a magnetic field in the copper wire coils of the generators. The magnetic field would induce an electrical current. The electrical current would then transfer into power transmission cables and travel into the outlets of homes and businesses.[115]

The extreme weather conditions of eastern Washington State proved unfavorable to the building project. Freezing winter temperatures reached well below zero degrees Fahrenheit during the winter of 1937, creating extensive problems with concrete. Summer temperatures reached as high as 108 degrees Fahrenheit. At times, temperatures remained over 100 degrees for weeks. Like all large construction projects, deaths occurred. Workers died from drowning in the frigid Columbia River, falling off scaffolds, and in one particularly unpleasant event a conveyer belt ripped a man apart. Unofficial records indicate somewhere between 72 to 89 men died while building Grand Coulee Dam. Compared to construction projects like the Panama and Suez canals, Grand Coulee Dam's death toll represented a very low number.[116]

President Roosevelt visited the dam's worksite twice, once in 1934 and again in 1937. During a speech there in 1937 the president conveyed, "We look forward not only to the great good this will do in the development of power but also in the development of thousands of homes, the bringing in of millions of acres of new land for future Americans."[117] Officials named the massive human-made lake behind Grand Coulee Dam in honor of the president.

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[115] "Hydroelectric Power Water Use," *The USGS Water Science School.* USGS: Science for a Changing World, http://ga.water.usgs.gov/edu/wuhy.html. Accessed November 9, 2013.

[116] Pitzer, *Grand Coulee: Harnessing a Dream*, 106-109.

[117] Franklin D. Roosevelt, "143 - Remarks at the Site of the Grand Coulee Dam, Washington."

In 1942, ahead of schedule and under budget, workers completed construction of Grand Coulee Dam. Originally conceived as an irrigation project with electricity as a secondary consideration, the dam's primary function had now changed. The United States had recently entered World War II. Pacific Northwest factories such as Boeing went into full swing to produce aircrafts for the war effort. Shipyards in Bremerton, Seattle, and Portland saw massive increases in the number of watercrafts built for use in the war. Downriver from Grand Coulee Dam the U.S. Government built the Hanford Atomic Site, a nuclear development facility. As part of the Manhattan Project, workers at Hanford developed the plutonium used in the bomb that dropped on Nagasaki, Japan. These wartime industries required massive quantities of electrical power. Thus, between 1942 and 1945, the production of electricity served as Grand Coulee Dam's sole function. After WWII ended President Truman stated, "Had it not been for the immense power dams on the Columbia River, it would have been much harder to win World War Two."[118]

The largest concrete dam in the world, Grand Coulee Dam contains 21,154,000 tons of concrete. That equals enough concrete to build a two lane highway around the entire perimeter of the continental United States. Grand Coulee Dam generates more than 21 billion kilowatt-hours of electricity each year. The total generating capacity comes to 6,809 megawatts of power, compared to Hoover Dam's much smaller 2,078 megawatts of power. Covering 11 western states, Grand Coulee Dam represents the leading producer of hydroelectricity in the United States. It provides 2.3 million households with electrical power each year.[119]

[118] Harry S. Truman, "Rear Platform and Other Informal Remarks in Oregon, June 11, 1948," *Harry S. Truman Library and Museum.* http://www.trumanlibrary.org/publicpapers/index.php?pid=1664. Accessed October 28, 2013.

[119] "Grand Coulee Dam Statistics and Facts,"*Reclamation: Managing Water in the West.* U.S. Department of the Interior: Bureau of Reclamation, no date given. http://www.usbr.gov/pn/grandcoulee/pubs/factsheet.pdf. Accessed September 29, 2013.

Grand Coulee Dam and the Environment

From an ecofriendly perspective, hydroelectricity symbolizes a much cleaner means of producing energy than many other methods. Unlike burning fossil fuels and splitting uranium atoms, hydroelectric dams generate power without releasing air pollution or radiation. Some people believe however that hydropower comes at too high a price. In order to produce a *hydraulic head*, engineers must take possession of a significant amount of steady-flowing water. Achieving this means building a sizeable dam, which itself requires large quantities of energy. Building dams on fast-flowing, bountiful rivers near deep gorges works best. Such settings often occur in isolated regions of uncommon, virginal beauty.[120] The ravine where the Bureau of Reclamation built Grand Coulee Dam exemplified such a place. In 1812 fur trapper Alexander Ross described the coulee as "…one of the most romantic picturesque and marvelously formed chasms west of the Rocky Mountains."[121]

Erecting Grand Coulee Dam backed up the Columbia River for 150 miles (figure 32). The reservoir it created, Franklin D. Roosevelt Lake, expanded as far as the Canadian border. It represented the largest lake or reservoir in the State of Washington. Roosevelt Lake drowned a number of towns along the Upper Columbia River. It also completely immersed Kettle Falls, an ancient Native American fishing site (figure 33).

In the Great Plains of North America, buffalo represented the mainstay of life for Native American tribes. For Native Americans along the Columbia River, salmon represented the mainstay of life. The vast numbers of salmon made them easy prey to tribal people. Smaller streams choked with mature salmon during the spring and fall salmon runs. Writing in his journal

[120] Henry Petroski, *The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems* (New York: Random House, Inc. 2011), 157.

[121] Pitzer, *Grand Coulee: Harnessing a Dream,* 5.

during the famous Expedition of the Corps of Discovery, William Clark frequently commented on the abundance of salmon in the Columbia River.[122] The migrations of salmon governed the tribes' economies, their customs, and their religions. Much of their daily activities centered on preparing for the salmon harvests that would sustain them all year long. They dried the salmon and stacked them like cordwood. Consuming and trading the dried salmon throughout the year, tribes of the Columbia Plateau gave honor to the delicious fish that kept their families and communities nourished.[123]

In June 1940 an emotional ceremony took place at Kettle Falls. Before it engulfed into its watery grave, Native Americans from throughout the Pacific Northwest said goodbye to the famed fishing spot. The following year as completion of Grand Coulee Dam approached, the waters behind the massive edifice rose drowning all natural and human-made structures (figure 34). As a child, Nancy St. Paul Picard, a woman from the nearby Colville Indian Reservation witnessed the immersion of her hometown. As she stood on the west bank Ms. Picard saw the house she had lived in all her life disappear under the new reservoir. She told friends, "I howled in grief when I saw a part of my family's home partially visible beneath the water. It had a ghostly appearance as I looked at it."[124] Destruction of the natural habitat triggered even bigger heartache. Losing the salmon runs generated immense cultural and economic loss to residents of the reservation.

The Colville Indian Reservation consisted of twelve confederated tribes including the famous Nez Perce. Led by Chief Joseph in 1876, the Nez Perce had fought a valiant war against

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[122] William Clark, "November 11th Monday 1805" *The Journals of the Corp of Discovery.* *http://lewisandclarkjournals.unl.edu/read/?_xmlsrc=1805-11-11&_xslsrc=LCstyles.xsl.* Accessed August 18, 2013.

[123] Ibid., 215-224.

[124] Lawney L. Reyes, *B Street: The Notorious Playground of Coulee Dam.* (Seattle: University of Washington Press, 2008), 148.

the U.S. Army. Author Lawney Reyes, born in 1931 and a member of the Sinixt tribe, spent much of his childhood on the Colville Indian Reservation. In his book *B Street: The Notorious Playground of Coulee Dam,* Reyes conveyed the tremendous sadness native peoples experienced over losing their homes and food sources. Reyes recalled Bureau of Reclamation officials hiring non-native crews to remove bodies from Indian burial grounds. During the relocation process many of the non-native workers plundered ancient graves for Indian relics. Numerous unmarked graves remained buried and continue to linger under the riverbed today.[125]

Before constructing Grand Coulee Dam the federal government had promised the tribes free electricity in exchange for their losses. Yet, after completion of the dam, Colville tribal residents paid the highest electrical rates in the State of Washington. The government had also promised them a steady supply of canned salmon in payment for the loss of salmon hauls. The promised canned salmon rarely arrived.[126] A respected leader of the Colville Tribal Council summed up the frustrations of her people when she stated, "We had a beautiful way of life. We were rich. The dam made us poor…The promises made by the government were written in sand and then washed away and covered with water when the river rose."[127]

Prior to raising Grand Coulee Dam (figure 35), salmon and other migratory fish traveled as far inland as the Continental Divide in the Northern Rocky Mountains. Salmon swam up the Columbia River and its major tributaries throughout Washington, Oregon, and then deep into the tributaries of Idaho, Montana, and British Columbia. The rivers served as highways for adult salmon to return to their places of birth. Once home the mature salmon reproduced and died. After the eggs hatched, young salmon would travel downriver in a treacherous journey to the

[125] Ibid, 144; 145.
[126] Ibid., 145.
[127] Ibid., 146.

salty water of the Pacific Ocean. After three to five years, salmon returned to the freshwater rivers, traveling upstream to the mountains to partake in the remarkable life cycle again.[128]

Five breeds of salmon held great importance to the Columbia Plateau tribes. Silver (also called Coho salmon), Sockeye salmon, Humpback or Pink salmon, Chum salmon (also called Dog salmon), and Chinook salmon (also called King salmon) all migrated up the Columbia River and its tributaries. Of these five, Chinook salmon represented the most important food source to native peoples. Chinook salmon sometimes grew to five feet long and weighed up to 60 pounds. Trout also belong to the salmon family. Rainbow trout and steelhead trout possess the same primordial instincts as salmon do. They began life in freshwater, traveled perilous journeys to the ocean, then later, following their olfactory instincts, return to their freshwater birthplaces. White sturgeon, the largest freshwater fish in North America, also live in the Columbia River and experience life cycles similar to salmon and trout.[129]

During the Great Depression of the 1930s, merely surviving represented most people's primary goal in life. In the 1940s, winning the world war took precedence. During those decades environmental concerns rarely sat at the forefront of matters. Thus, most people deemed the economic contribution of the dam and irrigation project as far more important than the welfare of fish. Yet in some ways the environmental planning of Grand Coulee Dam signified a project ahead of its time. Fifteen years earlier the Federal Power Act of 1920 set regulations on developing hydroelectric power in the United States. It established protocols for the "…adequate

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[128] Netboy, *The Columbia River Salmon and Steelhead Trout: Their Fight for Survival,* 44.
[129] Ibid., 11-12.

protection, mitigation, and enhancement of fish and wildlife (including related spawning grounds and habitat)…"[130]

The U.S. Army Corps of Engineers built Bonneville Dam on the Lower Columbia River during the same years the U.S. Bureau of Reclamation built Grand Coulee Dam on the Upper Columbia River. At Bonneville Dam engineers installed fish ladders which offer migratory salmon and trout a means to get past the dam. Yet officials at Grand Coulee Dam decided against installing fish ladders. They reasoned the installation of large pumps for irrigation would soon take place. During late spring and early summer, young salmon would travel downriver to the Pacific Ocean. The huge irrigations pumps behind the dam would surely draw the young salmon into the pumps where they would die. Designers of the project believed placing fine mesh to protect juvenile fish would prove too difficult. In the end, Grand Coulee Dam lacked any kind of fish passage.[131]

Officials however explored different methods of maintaining salmon runs. To partially preserve what some believed embodied the greatest salmon run on earth, they implemented an experimental strategy. With the help of the U.S. Bureau of Indian Affairs and the U.S. Fish and Wildlife Services, the U. S. Bureau of Reclamation would set traps at Rock Island Dam which sat at the Middle Columbia River. The traps would ensnare adult salmon on their journey back up the Columbia. Trucks would then transport the captured salmon to hatcheries. For young fish born in the hatcheries, biologists would transplant them in streams below Grand Coulee Dam. They hoped the young salmon would identify the streams as their original homes and return to the area as part of the natural salmon cycle. The Bureau of Reclamation estimated the cost of the

[130] "Federal Power Act," *Senate and House of Representatives of the United States of America in Congress assembled,* June 10, 1920. http://www.house.gov/legcoun/Comps/Federal%20Power%20Act.pdf. Accessed October 28, 2013.

[131] Pitzer, *Grand Coulee: Harnessing a Dream*, 219; 223.

fish-saving project at $2.6 million with financing coming from the Grand Coulee Dam building fund.[132]

In 1939 the North Central Washington Upper Columbia River Salmon Conservation Project went into action. Many of the fish and eggs did not survive artificial transportation. In particular, very young salmon called fry did not fare well. Young salmon physiologically transformed from a fry stage to a fingerling stage to a smolt stage. Scientists at that time held little knowledge on the nutritional needs of the ever-changing young salmon. Considering however the limited knowledge of salmon biology at that time, many mature salmon survived the preservation effort. In addition, during the conservation project biologists learned much about the life patterns of salmon. Nevertheless, without permanent fish ladders in place, Grand Coulee Dam cut off nearly half the entire length of the Columbia River. During the first several years after raising the enormous dam, witnesses observed thousands and thousands (possibly millions) of salmon attempting to penetrate the concrete barrier. In time the fish perished.[133]

Surprisingly, the Canadian bureaucrat responsible for overseeing Canada's river wildlife held little concern for the Columbia River salmon. In 1934 officials from the Canadian Legation in Washington, D.C. realized a problem would soon occur. They recognized that without the installation of fish ladders, Grand Coulee Dam would completely block salmon runs heading for the international border. The Canadian Legation contacted the Minister of Fisheries in Ottawa. The Canadian minister replied 11 days later with the following statement; "The assumption that there is no commercial salmon fishery on the Columbia River in Canada is correct, and hence

[132] Ibid., 226.

[133] John Harrison, "Grand Coulee Dam: Impacts on Fish," *Columbia River History,* Northwest Power and Conversation Council, 2010. http://www.nwcouncil.org/history/GrandCouleeImpactsOnFish. Accessed on October 13, 2013.

Canadian interests in that respect will not be affected if the dam at Grand Coulee is not equipped with fishway facilities."[134]

Erecting Grand Coulee Dam ushered in an era of mammoth dam building on the Columbia River. At present 14 major dams block the once rough-running river on its journey to the sea. Instead of swift rapids the Columbia River now consists mostly of elongated lakes one after another from Canada to the Bonneville Dam near Portland, Oregon. The once brisk, clear river now flows sluggish and murky. The lethargic current creates an inhospitable environment for salmon and other fish once so abundant in the Columbia River. Dams also pushed out terrestrial wildlife, replacing them with factories and other structures that caused pollution. In an effort to mitigate some of the environmental damage done from building Grand Coulee Dam, the government created Lake Roosevelt National Recreation Area. Operated by the U.S. National Park Service, this wildlife region contains nearly 100 species of mammals, 200 species of birds, and many reptiles and amphibians.[135]

Because of its direct relationship to irrigation and the Columbia Basin Project, Grand Coulee Dam represents the only dam on the Columbia River operated by the U.S. Bureau of Reclamation. The U.S. Army Corps of Engineers operates several of the other dams on the river. Bonneville Power Administration, a federal agency based in the Pacific Northwest runs three of the dams for hydroelectric power. In 1980 the federal government created yet another Columbia River agency, the Northwest Power and Conservation Council. With public participation the agency seeks to safeguard the region's electrical systems while also protecting and improving natural life forms. In addition to federal agencies, five local utility districts own and operate

[134] Pitzer, *Grand Coulee: Harnessing a Dream,* 224-225.

[135] "Lake Roosevelt National Recreation Area," *National Park Service,* U.S. Department of the Interior. http://www.nps.gov/laro/index.htm. Accessed November 3, 2013.

dams on the Columbia River. These dams operate with the cooperation of various native tribes. This demonstrates local interests of damming the river in addition to federal interests.

Columbia Basin Project

Immediately following World War II an emphasis remained on hydropower. New industries attracted by cheap, abundant electricity sprang up almost overnight in the Pacific Northwest. Soon however, interest swung back to the original intention of Grand Coulee Dam – irrigation. Once completed the two products of Grand Coulee Dam – water reclamation and electrical energy – would inextricably unite to form one entity. In a perpetual cycle, the large pump plant would lift water into the siphons by using power produced by the dam from water surging through the turbines. Aside from Grand Coulee Dam, the complex irrigation system would include reservoirs, siphons, main canals, feeder canals, tunnels, weirs, wasteways, drains, and ditches. In the end, building the Columbia Basin Project would embody a larger, more complicated, and more costly engineering feat than constructing Grand Coulee Dam had.[136]

In his 1948 State of the Union Address, Roosevelt's successor President Harry S. Truman discussed moving forward with the west's reclamation projects. He told the audience, "We must expand our reclamation program to bring millions of acres of arid land into production, and to improve water supplies for additional millions of acres."[137] So began the irrigation project citizens of central-eastern Washington State had long dreamed of.

Rolling into the desert like barbarian hordes, the mighty earth-moving machines arrived. Large tractors using fortified steel cables uprooted massive quantities of sagebrush, hard soil,

[136] Pitzer, *Grand Coulee: Harnessing a Dream* 277.

[137] Harry S. Truman, "Annual Message to the Congress on the State of the Union, January 7, 1948," *Harry S. Truman Library and Museum.* http://www.trumanlibrary.org/whistlestop/tap/1748.htm. Accessed October 20, 2013.

and deeply embedded rocks. Behind the tractors came more large machinery that smoothed the land of knolls, dips, and curves. More large machinery arrived to dig ditches as broad as 40 feet wide. Mixer trucks appeared pouring huge amounts of concrete to line the main canals, feeder canals, tunnels, and siphons (figures 36 & 37).[138]

At some areas, project planners took advantage of the channeled scars left behind by Ice Age Floods. At one key site however, between Dry Falls Dam and Billy Clapp Lake, engineers had to painstakingly dig a large channel through the hard, ancient basalt (figures 38 & 39). At the far end of Billy Clapp Lake they built Pinto Dam. The earthen wall contained one and a half million cubic yards of soil and rock, and reached 1,900 feet across (figure 40). Over the next several years the Bureau of Reclamation completed the Soap Lake Siphon, the West Canal, and the O'Sullivan Dam at Potholes Reservoir.[139]

The large pumps behind Grand Coulee Dam represented a crucial component of the project. The Bureau of Reclamation contracted with the California Institute of Technology to design the pumps, the largest ever built at the time (figure 41). Running just two of the pumps alone would require the entire electrical output of one of the dam's enormous generators. Together the 12 pumps would raise 720,000 gallons of water per minute. The boosted water would pour into Banks Lake, a 27 mile equalizing reservoir capable of storing over a million acre-feet of water (figure 42).[140]

Building Potholes Dam, now named O'Sullivan Dam, symbolized one of the major endeavors of the Columbia Basin Project. Costing nearly $10 million to build, this earthen dam would create Potholes Reservoir. O'Sullivan Dam would stretch over three and a half miles long.

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[138] Pitzer, *Grand Coulee: Harnessing a Dream*, 276; 281.
[139] Ibid., 278; 279.
[140] Ibid., 279.

At the time of its completion in 1948, O'Sullivan Dam would rank the fourth longest and fourth largest dam in the United States. Via canals, wasteways, and ditches, Potholes Reservoir would receive large volumes of drained-off irrigation water. At this point some of the water would recycle itself. It would flow away from the reservoir into the Potholes Canal where farmers would use the recaptured water to irrigate their fields. Potholes Reservoir would expand 45 square miles and hold nearly 400,000 acre-feet of water.[141]

Initially, classification of soil types and topography determined the type of irrigation method used. Flat farmlands used furrow irrigation while slanted farmlands used portable sprinkler systems. In the mid-1960s a new form of watering crops arrived on the scene. Center-pivot irrigation, also called circle irrigation (figure 43), allowed farmers to water on both flat and hilly lands. Circle irrigation proved a much better conserver of water than furrow and surface irrigation methods had.[142]

Work on the Columbia Basin Project continues today. The project delivers water to 650,000 acres, an area about the size of Rhode Island. Farmers and all others who use "project water" make yearly payments directly to the U.S. Bureau of Reclamation. The land that previously contained little but sagebrush now grows abundant yields of potatoes, sugar beets, apples, carrots, alfalfa, and many other important crops. Once harvested, foods must undergo processing and transporting. Thus, packaging firms, refineries, and trucking companies provide ample employment to local residents. The economic ripples continue outward to include farm equipment businesses, banks, attorneys, retail businesses, medical professionals, and much more.

[141] Ibid., 278.
[142] Ibid., 282-283.

Once economically stagnant, the Columbia Basin in central-eastern Washington State now stands as one of the most agriculturally dynamic areas in the United States.[143]

Columbia Basin Project and the Environment

Preparing land for irrigation greatly altered the character of the land. To illustrate the enormity of the terrestrial transformations, individuals can visualize the path irrigation water takes as it journeys to the farmlands. Water destined for farms begins at Grand Coulee Dam, one of the largest concrete structures ever built. Impounding the Columbia River at Grand Coulee Dam created the large, engulfing reservoir Franklin D. Roosevelt Lake. The huge pump-generator plant behind Grand Coulee Dam drives river water into another large human-made reservoir called Banks Lake. Two artificial rock and earth-filled dams, one at the north end and one at the south end, hold water in place at Banks Lake. Upon arriving at the south end of Banks Lake, water enters Dry Falls Dam where the Main Canal begins. About two miles south of Dry Falls Dam, water enters the two large Bacon Siphons, then the two large parallel underground channels, the Bacon Tunnels. Upon leaving the Bacon Tunnels, water travels above ground again in the continuation of the Main Canal.[144]

Next the water enters another large human-made reservoir, the six mile long Billy Clapp Lake. Water continues its southward journey through Billy Clapp Lake to earthen Pinto Dam. Pinto Dam contains nearly 1.5 million cubic yards of soil and rock. About three miles after leaving Pinto Dam, the latter portion of the Main Canal bifurcates into two major canal systems.

[143] Gina Bloodworth & James White, "The Columbia Basin Project: Seventy-Five Years Later," *Association of Pacific Coast Geographers: Central Washington University*, no. 70, 2008. http://muse.jhu.edu/journals/yearbook_of_the_association_of_pacific_coast_geographers/v070/70.bloodworth.html. Accessed August 10, 2013.

[144] Pitzer, *Grand Coulee: Harnessing a Dream*, 371-373.

The 82 mile long West Canal represents the westward then southward journey of canal water. The West Canal includes the inverted two and a half mile long Soap Lake Siphon, the Leech Creek Siphon, and a 9,280 foot long tunnel through Frenchman Hills.[145]

The longer East Low Canal represents the other primary canal that bifurcates from the Main Canal. It meanders in a long southward and sometimes eastward path before reaching yet another large human-made lake, the Scooteney Reservoir. Numerous lateral canals branch off from both the West Canal and the East Low Canal. Engineers lined many of the canals with concrete while other canals contain earth and rock as lining.[146]

The sizeable earth-filled O'Sullivan Dam and the human-made lake it creates, Potholes Reservoir, represent the lower-central portion of the Columbia Basin Project. Through a complex series of wasteways and drains the reservoir receives runoff water from irrigated farms located on the upper half of the project. The Potholes Canal, Eltopia Branch Canal, Wahluke Branch Canal, Royal Branch Canal, and Winchester Wasteway represent a portion of the many canals at the latter part of the project area.[147]

All these human-made edifices violated the natural characteristic of the land. Yet, despite the considerable quantities and magnitudes of the structures already in place, the Columbia Basin Project remains only two-thirds complete. The final one-third of the project, the East High Canal and its multiple structures, remains on indefinite hold. Since the 1970s this segment of the project has experienced intense financial and environmental debate.

The first attempt to build the East High Canal occurred in 1983. At that time authorities canceled the project after undergoing strong disagreement on the amount of funding the project

[145] Ibid., 373.
[146] Ibid.
[147] Ibid., 374.

would require. In 1994, after an eight-year-long second attempt to build the East High Canal, the launching of the project again ended in stalemate. That year the World Wildlife Organization listed several Columbia River salmon and steelhead on the Endangered Species Act.[148] Withdrawing more water from the Columbia River would further imperil the already-threatened salmon. A third attempt in 2001 to build the East High Canal ended when Washington State legislatures determined a need existed for more water storage.[149]

Dealing with the current canals already requires considerable time and cost. For instance, the salts found in freshwater that led to the demise of ancient Sumer still exist in today's rivers. The Columbia River carries its salts, now commonly referred to as Total Dissolved Solids (TDS), into the Pacific Ocean. The Columbia Basin Project however diverts some of the Columbia River's water to inland farms. When irrigation holds up the flow of water, a process called evapotranspiration occurs. Evapotranspiration involves water molecules dissipating into the air via regular evaporation combined with the transpiration of plants. This process intensifies TDS levels. Aware of the need to avoid salinity build-up in the soil, modern farmers must prepare their fields with adequate drainage.[150]

In addition to TDS levels, pesticides and fertilizers find their way into the regional water. High levels of these chemicals can potentially cause harm to people, salmon, and natural habitats. Much of the used irrigation water from the Columbia Basin Project pours into the Potholes Reservoir and the Scooteney Reservoir. Mindful that unwanted chemicals may enter

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[148] "Chinook Salmon." *National Oceanic and Atmospheric Administration. Northwest Regional Office*, no date given. http://www.nwr.noaa.gov/protected_species/salmon_steelhead/salmon_and_steelhead_listings/chinook/chinook_salmon.html. Accessed September 1, 2013.

[149] Tijs van Maasakkers, *The Role of Science in Water Management in Washington State*. Massachusetts Institute of Technology, 2008. http://web.mit.edu/dusp/epp/music/pdf/tijsfirstyearpaper.pdf. Accessed November 2, 2013.

[150] Pillsbury, "The Salinity of Rivers."

domestic groundwater and the Columbia River, authorities conduct frequent studies on water quality. The U.S. Bureau of Reclamation contracts with the U.S. Geological Survey to determine the level of chemicals in the Columbia Basin region. Between 2002 and 2004 the Geological Survey collected water samples from four drainage basins fed by the Columbia Basin Project. The comprehensive study evaluated levels of herbicides, insecticides, fungicides, dissolved oxygen levels, stimulants, water temperature, and more. Some of the tests exceeded Environmental Protection Agency criteria. However, many of the samples showed acceptable levels of water quality standards. Government agencies continue to closely watch TDS and other chemical levels in the Columbia Basin watershed.[151]

In 1944 officials established the 29,000 acre Columbia National Wildlife Refuge. Located near Potholes Reservoir, it serves as a sanctuary to various waterfowl, bald eagles, hawks, and migratory birds such as Sandhill cranes. At least 32 types of mammals also make their homes at the haven including coyote, mule deer, muskrats, bobcats, and the yellow-bellied marmot. Numerous fish, amphibians, and reptiles also live in the Columbia National Wildlife Refuge. Operated by the U.S. Fish and Wildlife Service, the agency allows hunting and fishing of some of the wildlife. Further north, Banks Lake Wildlife Recreation Area and several other sites along the Columbia River also provide havens for wildlife.[152]

Numerous government and non-profit agencies have instigated strategies to help the Columbia River's anadromous (migratory) fish. The Columbia River Inter-Tribal Fish Commission embodies one such agency. Functioning as a non-profit organization in Portland,

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[151] Richard J. Wagner, Lonna M. Frans, Raegen L. Huffman, *Occurrence, Distribution, and Transport of Pesticides in Agricultural Irrigation-Return Flow from Four Drainage Basins in the Columbia Basin Project, Washington, 2002-04, and Comparison with Historical Data.* U.S. Department of the Interior and U.S. Geological Survey. http://pubs.usgs.gov/sir/2006/5005/pdf/sir20065005.pdf. Accessed November 3, 2013.

[152] "Columbia National Wildlife Refuge," *U.S. Fish and Wildlife Service,* U.S. Department of the Interior, http://www.fws.gov/columbia/wildlife.html. Accessed October 10, 2013.

Oregon it consists of representatives from four Northwest Native American tribes. Their organization's primary goals include increasing fish populations in the Columbia River and its tributaries, and protecting tribal fishing rights. The commission provides financial support to the Hagerman Genetics Laboratory at the University of Idaho. Their research shows that salmon and steelhead trout possess highly adaptive capacities to conform to regional environments. Interpreting the chromosomal foundations for these adaptations helps scientists determine restoration policies and procedures.[153]

On November 13, 2013 the author of this thesis attended a meeting on rebuilding salmon populations. The Northwest Power and Conservation Council, a federally funded agency, conducted the meeting. The council strives to protect wildlife while also ensuring hydroelectric power for human needs. The meeting's agenda included discussion of the ongoing use of artificial production as a recovery method for salmon and steelhead populations. Members also discussed hatchery genetics and tagging programs. According to officials at the meeting, salmon and steelhead populations continue to improve.

During the second half of the twentieth century, irrigation developed into a quasi-religion in the Pacific Northwest. Water captured from the Columbia River had made the desert of eastern Washington State bloom. The government made environmental mistakes but they also made some amends. Authorities established wildlife havens and implemented various programs in an attempt to rectify some of the damage done. Sadly however, Native Americans of the Upper Columbia River and the backbone of their culture – the migratory salmon – paid a heavy and permanent price. To people living on the Colville Indian Reservation, the raising of Grand

[153] "Hagerman Genetics Laboratory," *Fishery Science.* Columbia River Inter-Tribal Fish Commission, 2013. http://www.critfc.org/fish-and-watersheds/fishery-science/hagerman-genetics-laboratory/. Accessed November 14, 2013.

Coulee Dam amounted to economic and cultural butchery. Sixty years later the federal government finally made partial compensation to the Colville tribes. Yet the ancient, intimate relationship between the Colville tribes and their time-honored rituals with salmon had passed into history.[154]

[154] Reyes, *B Street: The Notorious Playground of Coulee Dam,* 148.

CHAPTER IV: CONCLUSION

ENVIRONMENTAL ANALYSIS OF TWO WATER CANALS

President Theodore Roosevelt represented the individual most responsible for building the Panama Canal. His distant cousin President Franklin D. Roosevelt represented the individual most responsible for building the Columbia Basin Project. Neither man still held office when the endeavors reached their culmination. Yet their vision and determination significantly drove the projects in their initial and middle stages. In some respects the Roosevelt cousins' ideologies matched. In other aspects their ideologies differed. Likewise, the canal projects they spearheaded contained both similar and dissimilar features.

Dams

Building the Panama Canal and building the Columbia Basin Project required engineers to erect hydroelectric dams adjacent to the canals. For the Panama Canal, electricity produced by Gatun Dam serves as a means to power the canal locks and power the canal's lighting. For the Columbia Basin Project, electricity produced by Grand Coulee Dam serves as a means to power the large pumps that lift water from the Columbia River. In addition, the large reservoirs created by both dams provide the necessary water for use in the canals. In other words, neither the Panama Canal nor the Columbia Basin Project could exist without their mother dams.

Yet dams represent major intrusions to the environment. Large dams in particular, such as Gatun Dam and Grand Coulee Dam, completely transform aquatic biomes. Prior to the construction of a dam, the aquatic inhabitants live in a river ecosystem. Once a dam blocks a river the aquatic inhabitants must struggle to live in a lake ecosystem. River ecosystems and lake ecosystems differ greatly. Aquatic creatures in rivers had adapted to the fast-flowing water that stimulated ample amounts of dissolved oxygen. The sluggish flow of impounded rivers on the other hand fosters inadequate amounts of dissolved oxygen. The stagnant quality of dammed rivers also leads to the accumulation of contaminated sediment. The polluted sediment hinders healthy organic production. Fortunately for river biomes, the era of building colossal dams has more or less ceased.[155]

Natural Habitats

The destruction of natural habitats represents one of the biggest environmental offenses humans have perpetrated upon the earth. Both the Panama Canal and the Columbia Basin Project destroyed natural habitats. Salmon and other anadromous fish symbolize the Columbia Basin Project's most prominent victims. According to a 1995 National Academy of Sciences salmon study; "… Pacific salmon have disappeared from about 40 percent of their historical breeding ranges over the past 100 years and many of their remaining populations are severely reduced."[156] Because Native Americans of the Columbia Plateau possessed a deep affinity to salmon and the natural world, the destruction of wildlife also devastated their way of life.

Panama's tropical forests contained rich biodiversity with a tremendous plethora of plants and animals. Initially, scientists did not closely study the injury of natural habitats during the building of the Panama Canal. When engineers impounded Gatun Dam it created the huge human-made Gatun Lake. In the middle of Gatun Lake stands Barro Colorado Island, about

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[155] "Water Properties: Dissolved Oxygen," *The USGS Water Science School.* USGS: Science for a Changing World. http://ga.water.usgs.gov/edu/dissolvedoxygen.html. Accessed October 27, 2013.

[156] Brian Gorman, "National Academy of Sciences Salmon Study Reinforces Recovery Efforts Already Underway," *NOAA 95-R153,* 1995. *http://www.publicaffairs.noaa.gov/pr95/nov95/noaa95-r153.html*. Accessed September 5, 2013.

1,500 hectare in size. Once a hill surrounded by jungle, the island now serves as headquarters for the United States' Smithsonian Tropical Research Institute. As its name implies, this highly regarded organization remains dedicated to studying the ecology of rainforest plants and animals.

The sudden isolation of Barro Colorado Island had caused a grave upset in the balance of predator and prey. By 1923 when the Smithsonian Tropical Research Institute first established a station on the island, researchers found no signs of jaguars or spider monkeys. Once abundant in the area, officials did later record a sighting of a jaguar in 1983 and once again in 1993. In addition to the loss of jaguars and spider monkeys, officials state that, "White-lipped peccaries, and various smaller mammals, birds, amphibians, and reptiles have disappeared from Barro Colorado [Island] during the last 60 years."[157]

Water

Upon completion of the Columbia Basin Project, farmland that had once received six to ten inches of water in an entire year now received forty to sixty inches of water a year. Officials of the Bureau of Reclamation had anticipated changes in the composition and patterns of drainage. Yet nothing prepared them for the liquid onslaught that occurred from the dramatic increase of water in the once-parched land. In the early 1950s the severe excess of water created soggy lowlands and small lakes. Irrigation water washed out sections of highways and flooded

[157] E.G. Leigh, *Tropical Forest Ecology: A View from Barro Colorado Island*, (New York: Oxford University Press, 1999), 11.

people's basements. Over a period of several years the Bureau of Reclamation spent millions of public dollars building expensive drainage systems to remedy the serious overflow of water.[158]

Later, an unfinished portion of the Columbia Basin Project underwent a reverse problem; it suffered a severe dwindling of groundwater. In 2012 the U.S. Department of the Interior along with the State of Washington Department of Ecology conducted a study on aquifers in the Odessa Subarea. The Odessa Subarea falls within the Columbia Basin Project's boundaries but has not yet seen the installation of irrigation canals. Instead, farmers of the Odessa Subarea, anticipating the eventual use of canal water, pumped significant amounts of groundwater for use on their crops. The intensive pumping created a serious water shortage in the already sparse aquifers of the Columbia Plateau.[159]

After exploring various options to remedy the Odessa aquifer problem, the Bureau of Reclamation has moved forward with constructing the Weber Siphon Project. Building the costly Weber pipeline and siphon brings 20,000 new acres of farmland under the Columbia Basin Project's irrigation region. Although beneficial to the depleted aquifers, the Weber Siphon Project generates increased concern for environmentalists. Draining more water from the Columbia River means a continued assault on the already-jeopardized salmon runs of the Middle and Lower Columbia River.[160]

Conservationists advocate a complete avoidance of growing crops in areas that require heavy irrigation. They believe artificially supplying water to dry regions like eastern Washington State entails too high a financial and environmental cost. Environmentalists deem nature itself as

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[158] Pitzer, *Grand Coulee: Harnessing a Dream*, 292-294.

[159] "Odessa Subarea Special Study," *Columbia Basin Project: Study Update 2012.* U.S. Department of the Interior: Bureau of Reclamation, http://www.usbr.gov/pn/programs/ucao_misc/odessa/updates/update-july2012.pdf. Accessed November 3, 2013.

[160] Ibid.

the best determinant for regional plant growth. Drought-resistant plants grow well in dry climates while plants needing ample amounts of water grow well in rainforests.

The climate of the Panamanian Isthmus epitomizes a complete contrast to the climate of the Columbia Basin. Heavy annual precipitation creates dozens of rivers in the small nation of Panama. The volatility of the large Chagres River represented the primary reason the United States changed its design in 1906 from a sea-level canal to a summit canal with locks. With the new plan, water from the Chagres River no longer symbolized the enemy of the canal, but its friend.

Operating the canal does not require the use of ocean water, only freshwater. Lake Gatun, situated in the center of a large watershed, supplies the freshwater needed to utilize the locks. About 13,000 watercraft passages occur on the Panama Canal every year. Each passage requires the use of roughly 52 million gallons of freshwater. Deforestation and global warming have impacted the amount and availability of water. Agriculture represents the major cause of deforestation. In order to guarantee an ample supply of water, authorities have implemented programs aimed at encouraging farmers to use sustainable agricultural practices.[161]

Future of Water Canals

Water canals produced considerable economic and social benefits for humankind. Yet at the same time they produced negative effects on ecosystems (figures 44 & 45). Today, governments spend millions of public dollars to repair damage caused by water canals. In answer

[161] Stanley Heckado Moreno, "Impact of Development on the Panama Canal Environment." *Journal Of Interamerican Studies & World Affairs* 35, no. 3 (Fall 1993): 129, *Business Source Complete*. http://web.ebscohost.com.ezproxy1.apus.edu/ehost/detail?vid=7&sid=adb4b2cd-9ab2-48a9-865b-c8bcfa63e58e%40sessionmgr4003&hid=4101&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=bth&AN=9403030829. Accessed October 3, 2013.

to mounting worries, modern engineers strive to improve the designs of new canals. Before construction begins, they must thoroughly consider the complexities of the local natural systems. In some ways this makes building today's canals more difficult than in the past.

At the time of their formations, people deemed the Panama Canal and the Columbia Basin Project as highly successful endeavors of "man dominating nature." That common worldview stemmed from an Industrial Era perception of economic progress. The rise of industry had intensified people's craving to pilfer whatever they wanted from nature. Recognizing industrialization as an appalling means of mutilating nature simply did not cross most people's minds.

In recent decades the worldviews of many people have changed. Scientists have discovered our species has reached a point where we may seriously affect the health of our planet. People now know that nature operates on a series of sometimes fragile, inter-relations between living things. These complex associations between living entities include human beings. In other words, when societies move forward with an eye on preserving the environment, they move in a direction that also helps their own species – humankind.

APPENDIX

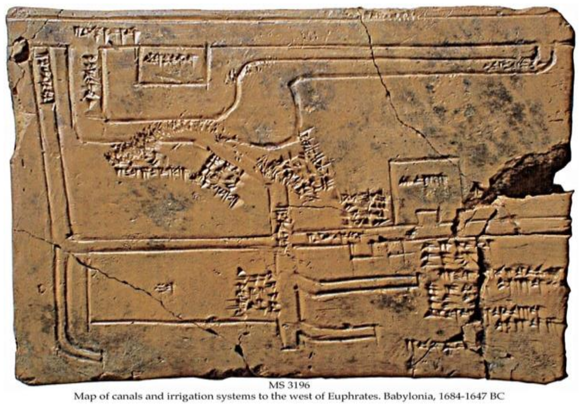

Figure 1: Clay tablet created by Mesopotamian canal engineer.
http://www.schoyencollection.com/smallercollect2.html

Figure 2: Bulla envelope from Sumer with 17 plain tokens representing wages at a rate of 1.8 measures of barley per day.
http://www.schoyencollection.com/math.html

Figure 3: Basin irrigation.
http://luirig.altervista.org/naturaitaliana/viewpics.php?title=Level+basin+irrigation+on+newly+planted+citrus+trees.+Yuma,+Az.

Figure 4: Furrow irrigation.
http://www.mississippi-crops.com/2011/06/23/drought-and-its-affect-on-pollination-and-corn-grain-fill/

Figure 5: Shaduf, a type of bucket and pulley invented in ancient Sumer.
http://www.groundwatercanada.com/index.php?option=com_content&task=view&id=1810&Itemid=134

Figure 6: Reed house lived in by people of the marshes in ancient Mesopotamia.
http://www.laputanlogic.com/articles/2004/01/24-0001.html

Figure 7: Windlass used to build qanats.
http://www.waterhistory.org/histories/qanats/

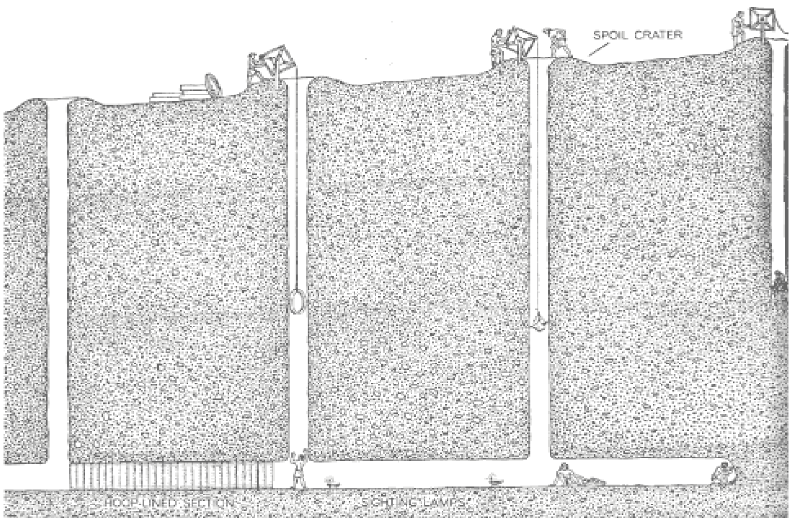

Figure 8: Constructing a qanat in ancient Persia.
http://www.waterhistory.org/histories/qanats/

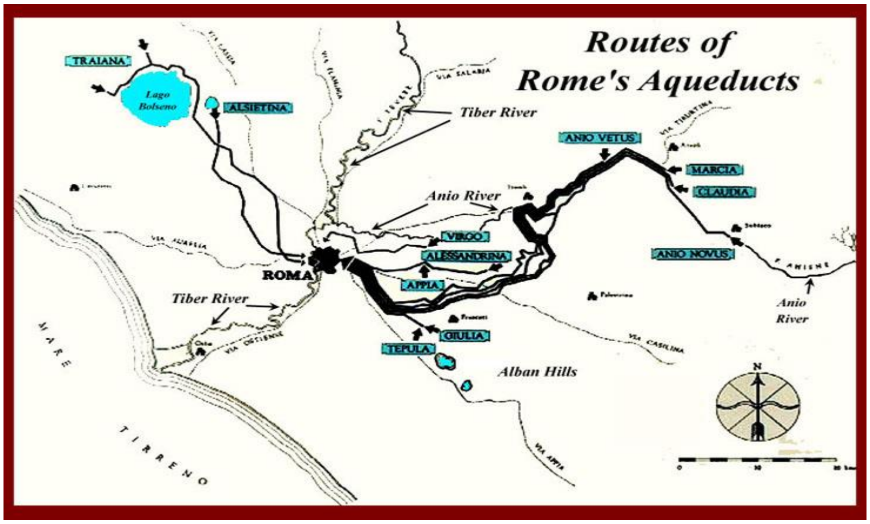

Figure 9: Routes of ancient Rome's main aqueduct canals.
http://www.mmdtkw.org/AU0303iAquaeMap.jpg

Figure 10: Ancient Roman viaduct.
http://www.history.com/news/history-lists/10-innovations-that-built-ancient-rome

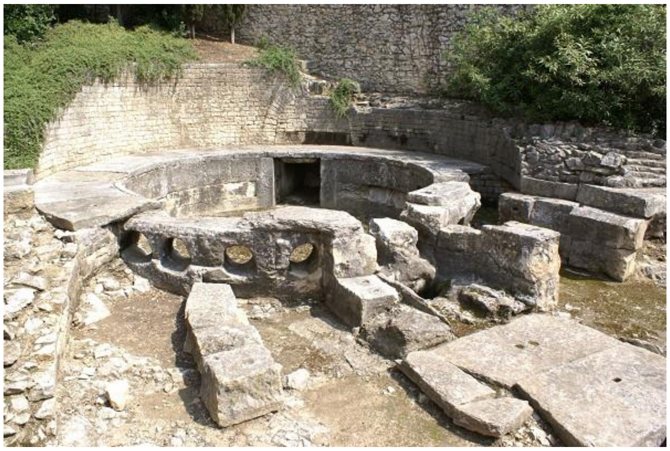

Figure 11: Castellum; part of a Roman aqueduct system in France.
http://fr.structurae.de/structures/data/?ID=s0008088

Figure 12: Panamanian Isthmus.
http://www.socialphy.com/posts/news-politics/8848/3-Short-Science-Stories-from-the-STRI.html

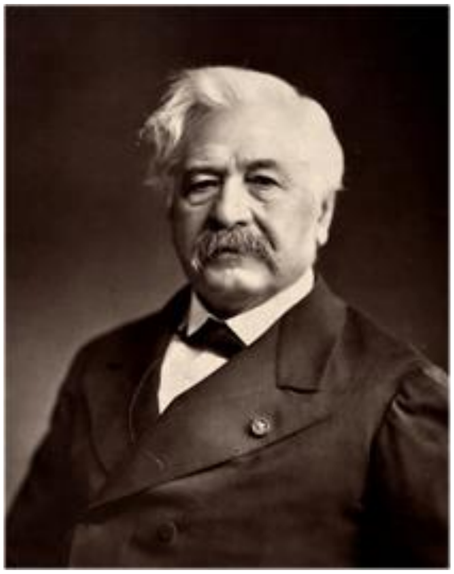

Figure 13: Count Ferdinand de Lesseps (1805-1894).
http://www.banrepcultural.org/blaavirtual/revistas/credencial/abril2011/ferrocarril-perdida-nacion

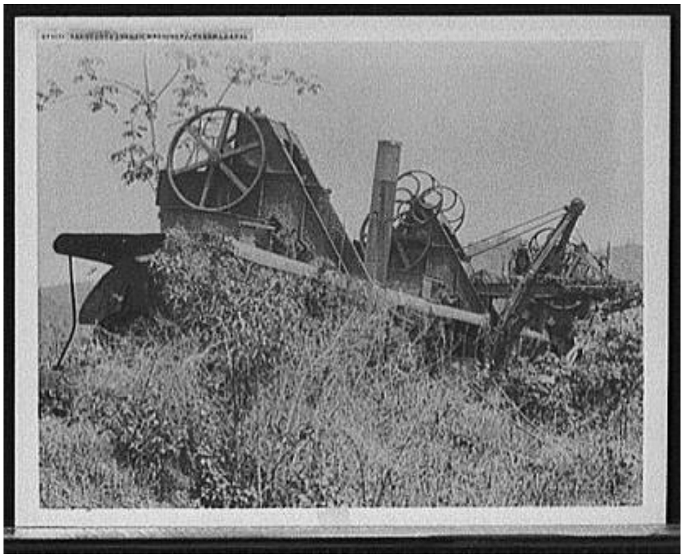

Figure 14: Abandoned machinery during French attempt at Panama, circa 1880s.
http://cnx.org/content/m34201/latest/

Figure 15: Manual laborers during United States' Panama Canal project.
http://www.latinamericanstudies.org/panama-canal3.htm

Figure 16: Steam shovel working in conjunction with railroad in Panama.
http://www.latinamericanstudies.org/panama-canal3.htm

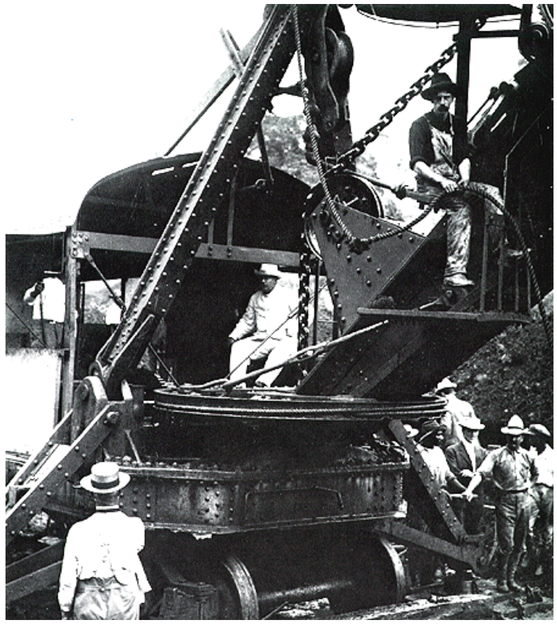

Figure 17: President Theodore Roosevelt posing on steam shovel at Panama Canal project, 1906.
http://www.latinamericanstudies.org/panama-canal3.htm

Figure 18: Construction of Gatun Dam at Panama Canal, circa 1908.
http://www.lindahall.org/events_exhib/exhibit/exhibits/civil/gatun_locks_2.shtml

Figure 19: Diagram of America's Panama Canal, now controlled by the Republic of Panama.
http://cnx.org/content/m34201/latest/


Figure 20: Construction of Panama Canal lock in 1912
http://www.kpbs.org/news/2011/jan/21/american-experience-panama-canal/

Figure 21: Accident at Culebra Cut, Panama; 1908.
http://www.lindahall.org/events_exhib/exhibit/exhibits/civil/culubra_cut.shtml

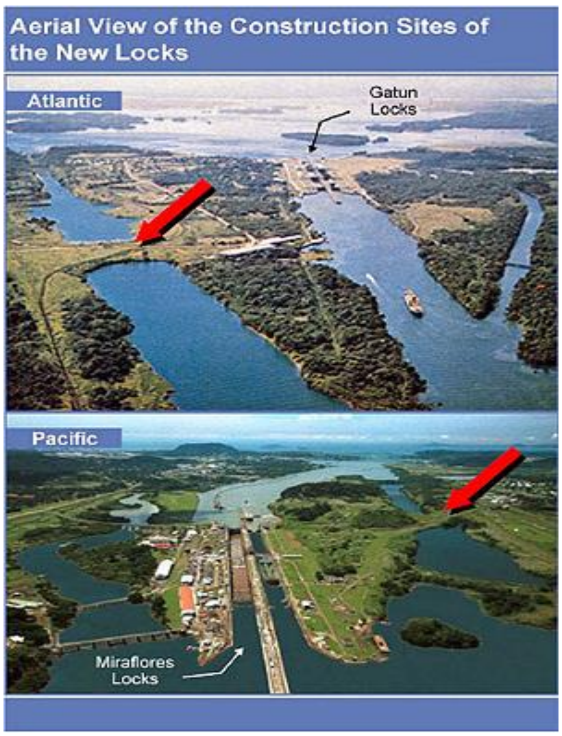

Figure 22: Sites of new, bigger locks at Panama Canal.
http://floridatransportationtoday.typepad.com/florida-transportation-ne/2011/03/new-panama-canal-locks-should-open-in-2014-look-for-bigger-ships-at-floridas-ports.html

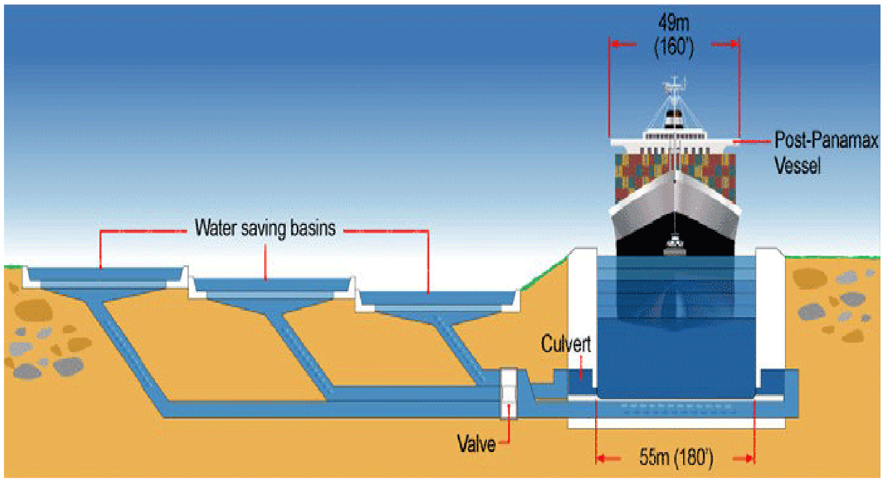

Figure 23: Cross view of Post-Panamax locks' water-saving system.
http://www.newworldencyclopedia.org/entry/File:Newlockscrosssection.jpg

Figure 24: Map of U.S. Bureau of Reclamation regions.
http://www.usbr.gov/main/about/addresses.html

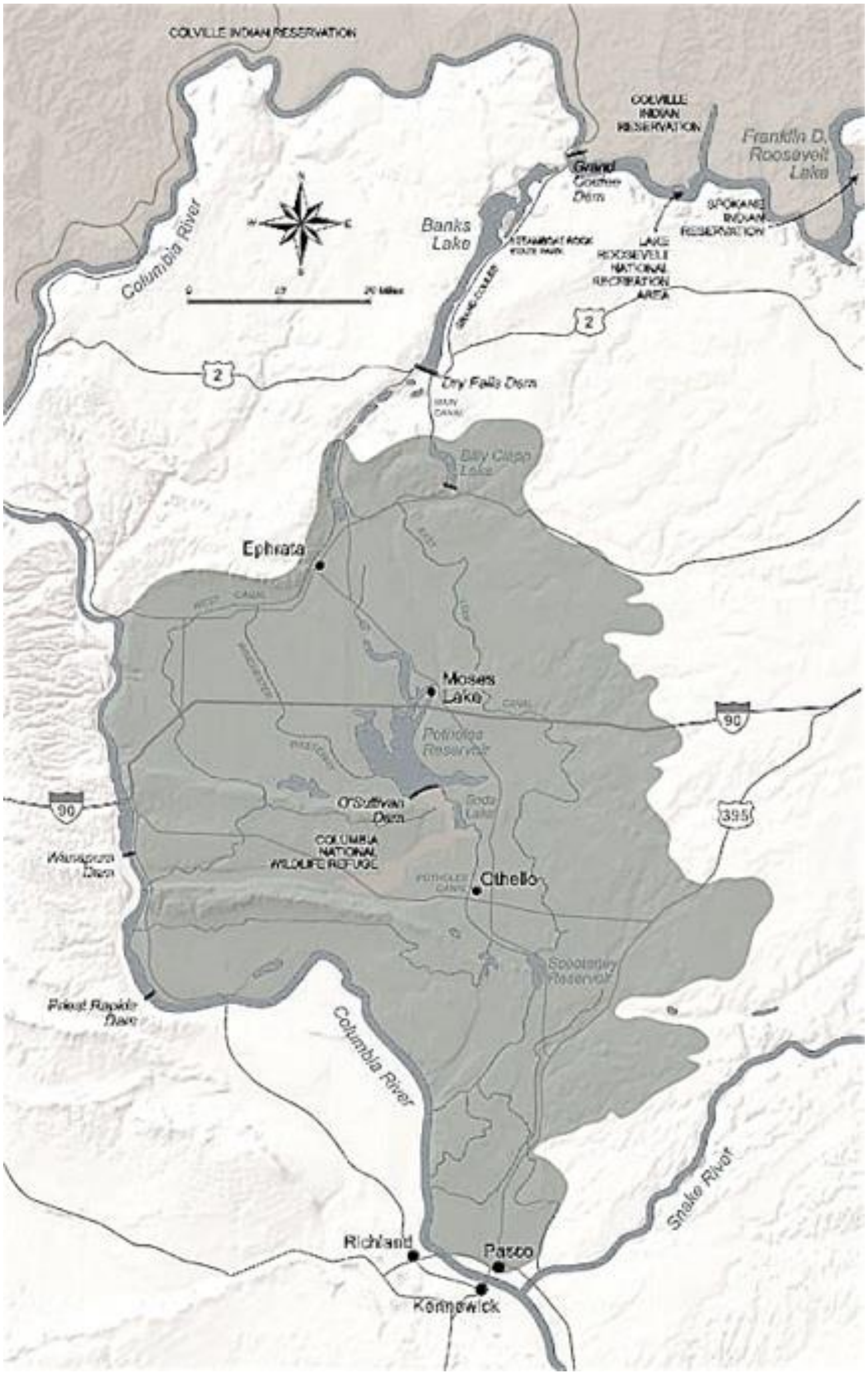

Figure 25: Columbia Basin Project.
http://columbia-institute.org/oa/odessa/CBP.html

Figure 26: Huge Columbia River flowing through dry, central-eastern Washington State.
http://www.willhiteweb.com/washington/vantage/ginkgo_petrified_forest/state_park_071.htm

Figure 27: Columbia River drainage area.
http://www.ecy.wa.gov/programs/wr/cwp/forecast/basin_map.html

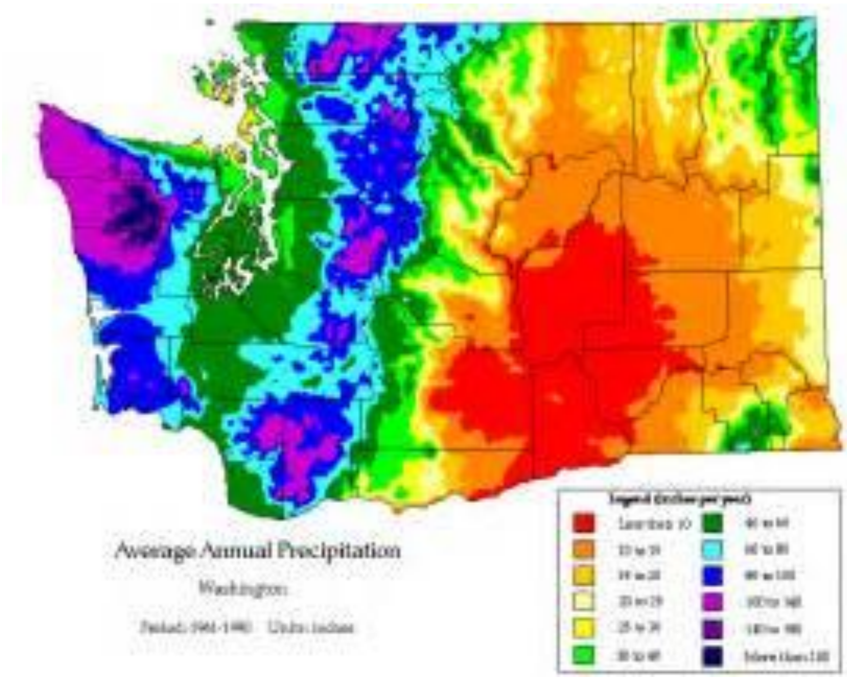

Figure 28: Stark contrasts in average annual rainfall in the State of Washington.
http://staff.washington.edu/rel2/geog100-UW/geog100a2B.html

Figure 29: Harsh scablands of eastern Washington State.
http://www.amateurgeologist.com/content/features/fieldtripreports/washington/floods.html

Figure 30: Early construction photo of Grand Coulee Dam, 1934.
http://content.lib.washington.edu/cdm4/item_viewer.php?CISOROOT=/loc&CISOPTR=999&CISOBOX=1&REC=1

Figure 31: Construction of Grand Coulee Dam, 1935.
http://www.gonzaga.edu/Academics/Libraries/Foley-Library/Departments/Special-Collections/Collections/James-OSullivan-Papers/default.asp

Figure 32: Aerial view looking northward/westward. Grand Coulee Dam in center of photo. Franklin D. Roosevelt Lake (reservoir) is the large body of water at center and to the right. The Columbia River continues its journey (upper portion of photo) after being impounded by Grand Coulee Dam. At far mid-left is a small portion of the large CBP reservoir, Banks Lake. http://commons.wikimedia.org/wiki/File:IMG_9097FDRlake.JPG

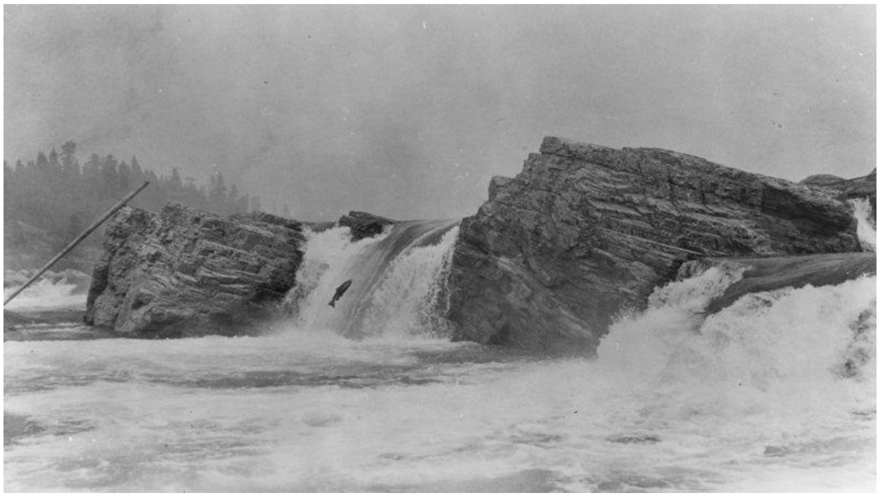

Figure 33: Kettle Falls before it disappeared below Franklin D. Roosevelt Lake (reservoir); photo taken in about 1900.
http://www.nwcouncil.org/media/24356/kettle2.jpg

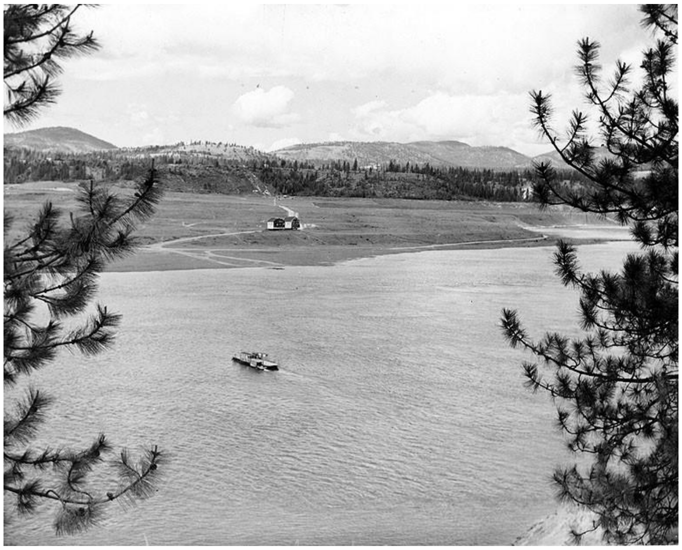

Figure 34: Moving Inchelium High School gymnasium, the last large building removed from the area before Roosevelt Lake (reservoir) waters rose past the timberline in 1941. http://content.lib.washington.edu/cdm4/item_viewer.php?CISOROOT=/grandcoulee&CISOPTR=82&CISOBOX=1&REC=1

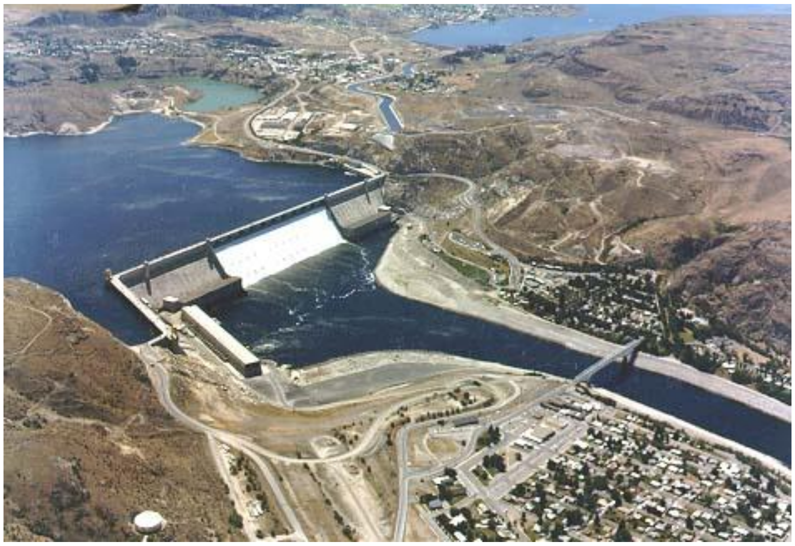

Figure 35: Grand Coulee Dam looking south-eastward. Franklin D. Roosevelt Lake (reservoir) is at center-left. First stages of Columbia Basin Project; feeder canal in upper center pouring into Banks Lake reservoir in upper right part of photo. http://serc.carleton.edu/images/eslabs/drought/grand_coulee_dam.jpg

Figure 36: Construction of Columbia Basin Project's West Canal in 1947.
http://www.trumanlibrary.org/photographs/displayimage.php?pointer=5825&people=&listid=4

Figure 37: Columbia Basin Project's Soap Lake Siphon.
http://www.nps.gov/history/history/online_books/dams/columbia_basin/sec2.htm

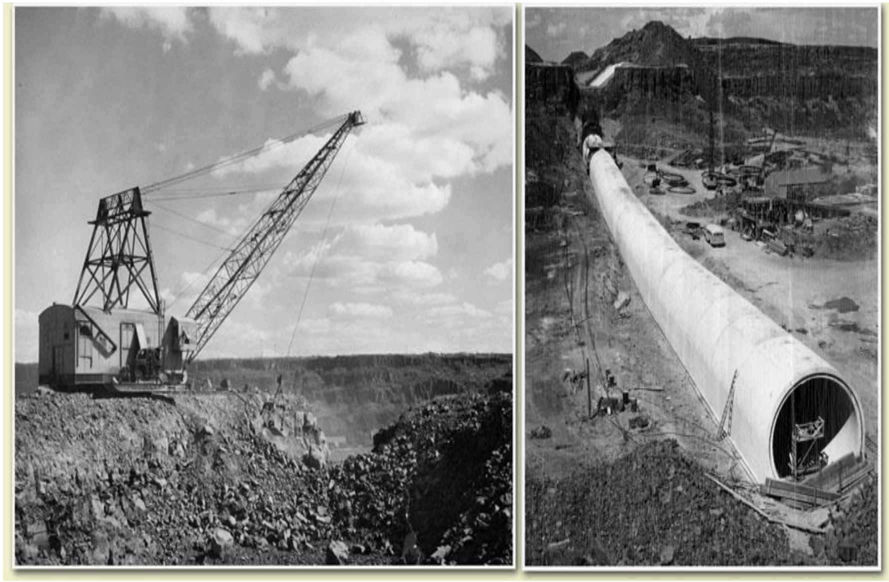

Figure 38: Construction of Columbia Basin Project's Main Canal through the ancient hard basalt between Dry Falls Dam and Billy Clapp Lake.
http://iceagefloods.blogspot.com/2008/10/billy-clapp-lake.html

Figure 39: Part of Columbia Basin Project's Main Canal in upper-center background. On the left is Summer Falls (site of 1978's tragic triple drowning) pouring into Billy Clapp Lake. U.S. Bureau of Reclamation hydro-facility is on right. Photo clearly reveals ancient basalt lava flows of eastern Washington State.
http://iceagefloods.blogspot.com/2008/10/billy-clapp-lake.html

Figure 40: Pinto Dam at south end of Billy Clapp Lake with continuation of Main Canal on left front. Photo also shows the dryness and bleakness of the land.
http://www.nwcouncil.org/media/23886/cbp.jpg

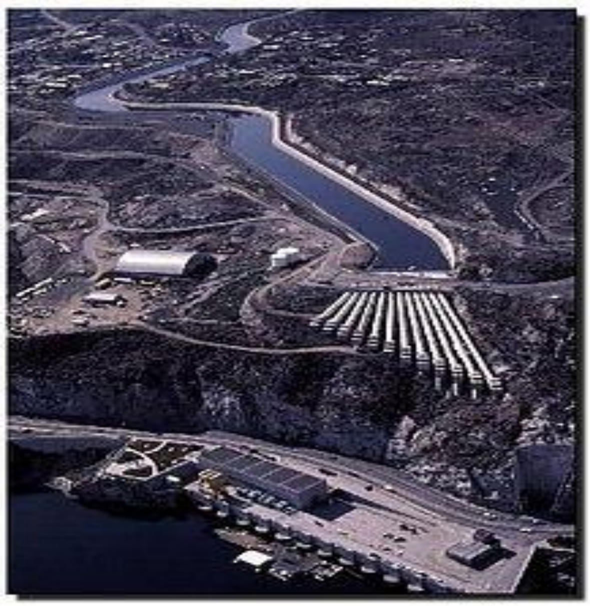

Figure 41: Where the Columbia Basin Project begins; Grand Coulee Pump-Generating Plant. Twelve colossal pumps/pipes lift river water into feeder canal behind Grand Coulee Dam (dam not shown in photo). Franklin D. Roosevelt Lake reservoir at bottom left.
http://ookaboo.com/o/pictures/picture/12470594/Pump_Generating_Plant_and_Roosevelt_Lake

Figure 42: Banks Lake; one of several large reservoirs created by the Columbia Basin Project.
http://www.summitpost.org/banks-lake/455578/c-455571

Figure 43: Circle irrigation sprinklers.
http://columbia-institute.org/oa/odessa/Odessa%20Aquifers.html

Figure 44: Weed infestation in abandoned Florida canal.
http://plants.ifas.ufl.edu/manage/overview-of-florida-waters/waterbody-types/canals

Figure 45: Abandoned canal in Florida revealing polluted sediment build up.
http://plants.ifas.ufl.edu/manage/overview-of-florida-waters/waterbody-types/canals

GLOSSARY

Alluvial: Soil formed in river valleys and deltas from sediment material washed down by flowing water.

Anadromous: Type of fish that migrates from saltwater areas to freshwater areas for spawning.

Aqueduct canal: Artificial channel that moves water from one location to another, often across long distances.

Aquifer: Underground layer of rock or sand that naturally holds water.

Basin irrigation: Irrigating land by surrounding it with embankments to form a basin and flooding it with water.

Bucyrus steam shovel: Large excavating machine used to remove spoil.

Castella: Plural form of castellum.

Castellum: Small reservoir located at end of an aqueduct canal, used for distributing water into various channels.

Channeled scablands: Dry, harsh region in central-eastern Washington State.

Cofferdam: Temporary enclosure that keeps water and soil away while a dam undergoes construction.

Evapotranspiration: Water molecules returning to the air through the dual processes of evaporation from soil and transpiration from plants.

Feeder canal: Conducts water to a main canal or reservoir.

Flash lock: Early type of lock using only one gate.

Fossa: An indentation, ditch, or trench.

Furrow irrigation: Irrigating land by creating small parallel channels along a field in the direction of a predominant slope.

Hatchery: Human-controlled locale where fish eggs are hatched.

Inverted siphon: Pipe that dips below a barrier to form a u-shaped course.

Marshland: Region characterized by swamps and bogs.

Miasma: Injurious or toxic mists.

Mughani: Ancient Persian skilled at building qanats.

Navigation canal: Navigable canal used to transport cargo and people (also called transport canal or waterway canal).

Pound lock: First used in ancient China and very common today, pound locks have gates at two ends to control water levels.

Qanat: Sloping tunnel dug into a hillside until it reaches an underground water source.

Salination: Process of salt accumulating in soil or water.

Scratch plow: Primitive plow with a blade usually pulled by a large domestic animal.

Shaduf: Device that raises water using a hanging pole that swivels a bucket on one side and a weight on the other.

Sluice: Water channel controlled at its head by a gate.

Spoil: Dirt or stones excavated and removed from its original site.

Staunch: Gate that rises vertically, used to control water-levels.

Summit canal: Artificial waterway that must overcome higher elevation.

Transport canal: Navigable canal used to transport cargo and people.

Viaduct: Raised roadway typically comprising of a series of short spans buttressed on arches.

Waterway canal: Navigable canal used to transport cargo and people.

Weir: Small dam built to divert flow or change water level.

Windlass: Contraption that uses a rope coiled around a spinning cylinder to lift spoil.

BIBLIOGRAPHY

Primary Source Material

Babylonian Legends of the Creation: and the Fight Between Bel and the Dragon as Told by Assyrian Tablets of Ninevah, no date given. British Museum, 1921. http://djvued.libs.uga.edu/BL1620xB7/1f/babylonian_legends_of_creation.pdf. Accessed October 8, 2013.

Canby, Jeanny Vorys. "A Monumental Puzzle: Reconstructing the Ur-Nammu Stela." *Expedition*, no date given. 29. 2001. *54 – 64*. http://www.penn.museum/documents/publications/expedition/PDFs/29-1/Monumental1.pdf. Accessed July 22, 2013.

Clark, William. "November 11th, Monday 1805." *The Journals of the Corp of Discovery*. *http://lewisandclarkjournals.unl.edu/read/?_xmlsrc=1805-11-11&_xslsrc=LCstyles.xsl*. Accessed August 18, 2013.

"Convention with Panama for the Construction of the Panama Canal." *Convention with Panama for the Construction of the Panama Canal*, 1903. January 9, 2009: 1. http://web.ebscohost.com.ezproxy1.apus.edu/ehost/detail?vid=4&sid=36b9f4c8-f764-4145-a3a0-0fa4146d8f39%40sessionmgr13&hid=18&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=aph&AN=21212249. Accessed July 28, 2013.

"Environmental Impact Study for the Panama Canal Expansion Project." *Executive Summary*. 2007. http://www.pancanal.com/eng/expansion/rpts/environment/eisa/exec-summary.pdf. Accessed July 27, 2013.

"Federal Power Act." *Senate and House of Representatives of the United States of America in Congress Assembled*, June 10, 1920. http://www.house.gov/legcoun/Comps/Federal%20Power%20Act.pdf. Accessed October 28, 2013.

Frontinus, Sextus Julius. *De Aqueducta Urbis Romae,* First century AD. Cambridge Classical Texts and Commentaries, 2004. http://site.ebrary.com/lib/apus/docDetail.action?docID=10130463. Accessed August 30, 2013.

"Grand Coulee Dam Statistics and Facts." *Reclamation: Managing Water in the West.* U.S. Department of the Interior: Bureau of Reclamation, no date given. http://www.usbr.gov/pn/grandcoulee/pubs/factsheet.pdf. Accessed September 29, 2013.

Kerr, Robert S. *Characteristics and Pollution Problems of Irrigation Return Flow*. U.S. Department of the Interior: Federal Water Pollution Control Administration, 1969. http://nepis.epa.gov/Exe/ZyNET.exe/9101AMX0.txt?ZyActionD=ZyDocument&Client=EPA&Index=Prior%20to%201976&Docs=&Query=%28salt%29%20or%20%28salt%29%20OR%20FNAME%3D%229101AMX0.txt%22%20AND%20FNAME%3D%229101AMX0.txt%22&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX%20DATA%5C70THRU75%5CTXT%5C00000019%5C9101AMX0.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=10&ZyEntry=1. Accessed October 6, 2013.

Kramer, Samuel Noah. “Farmers’ Almanac.” No date given. *Sumerians: Their History, Culture, and Character.* Chicago: The University of Chicago Press, 1963.

Lukesh, G.R. “Columbia River and Minor Tributaries.” *House Document No. 103, 73rd Congress,* 1932.1st Session: 308 Reports, p.84. StreamNet: Fish Data for the Northwest. http://www.streamnetlibrary.org/?page_id=68. Accessed September 28, 2013.

“Magna Carta; Clause 41,” 1215 CE. *Treasures in Full: The British Library Board*. http://www.bl.uk/treasures/magnacarta/translation/mc_trans.html. Accessed August 27, 2013.

“Odessa Subarea Special Study.” *Columbia Basin Project: Study Update 2012.* U.S. Department of the Interior: Bureau of Reclamation, 2012. http://www.usbr.gov/pn/programs/ucao_misc/odessa/updates/update-july2012.pdf. Accessed November 3, 2013.

Pabst, Arthur F. *Some History and Hydrology of the Panama Canal.* U.S. Army Corps of Engineers: Institute for Water Resources, 2000. http://www.hec.usace.army.mil/publications/TechnicalPapers/TP-159.pdf. Accessed November 8, 2013.

Pliny the Elder. *Natural History,*79 CE. Cambridge: Harvard University Press, 1938.

Reyes, Lawney L. *B Street: The Notorious Playground of Coulee Dam.* Seattle: University of Washington Press, 2008.

Roosevelt, Franklin D. “143 - Remarks at the Site of the Grand Coulee Dam, Washington, August 4, 1934.” *The American Presidency Project*. http://www.presidency.ucsb.edu/ws/index.php?pid=14732#axzz2i6hSCde9. Accessed October 18, 2013.

Schoyen, Martin. "MS3196: Map of Canals and Irrigation Systems to the West of Euphrates, etc." (1684 – 1647 BCE). *Schoyen Collection: 740 Manuscripts Spanning 5000 Years.* 2009. http://www.schoyencollection.com/smallercollect2.html#top Accessed July 22, 2013.

"Story of the Flood." *The Epic of Gilgamesh*, no date given. http://www.ancienttexts.org/library/mesopotamian/gilgamesh/tab11.htm. Accessed October 8, 2013.

Truman, Harry S. "Annual Message to the Congress on the State of the Union, January 7, 1948." *Harry S. Truman Library and Museum.* http://www.trumanlibrary.org/whistlestop/tap/1748.htm. Accessed October 20, 2013.

Truman, Harry S. "Rear Platform and Other Informal Remarks in Oregon, June 11, 1948." *Harry S. Truman Library and Museum.* http://www.trumanlibrary.org/publicpapers/index.php?pid=1664. Accessed October 28, 2013.

Wagner, Richard J., Lonna M. Frans, Raegen L. Huffman. *Occurrence, Distribution, and Transport of Pesticides in Agricultural Irrigation-Return Flow from Four Drainage Basins in the Columbia Basin Project, Washington, 2002-04, and Comparison with Historical Data.* U.S. Department of the Interior and U.S. Geological Survey, 2005. http://pubs.usgs.gov/sir/2006/5005/pdf/sir20065005.pdf. Accessed November 3, 2013.

Secondary Source Material

Bakalar, Nicholas. "Ancient Canals in Andes Reveal Early Agriculture." *National Geographic News*, 2005. http://news.nationalgeographic.com/news/2005/12/1205_051205_peru_canals.html. Accessed July 5, 2013.

"Bureau of Reclamation – About Us." *Reclamation: Managing Water in the West.* U.S. Department of the Interior, 2013. http://www.usbr.gov/main/about/. Accessed August 25, 2013.

"Bureau of Reclamation – Columbia Basin Project." *Reclamation: Managing Water in the West.* U.S. Department of the Interior, 2013. http://www.usbr.gov/projects/Project.jsp?proj_Name=Columbia+Basin+Project. Accessed August 27, 2013.

Blair, John. "Waterways and Canal-Building in Medieval England." *Medieval History and Archaeology*. New York: Oxford University Press, 2007.

Bloodworth, Gina & White, James. "The Columbia Basin Project: Seventy-Five Years Later." *Association of Pacific Coast Geographers:* Central Washington University, no. 70, 2008. http://muse.jhu.edu/journals/yearbook_of_the_association_of_pacific_coast_geographers/v070/70.bloodworth.html. Accessed August 10, 2013.

Caffyn, Douglas. "Boats on our Rivers Again" *Caffyn on Rivers*, 2011. http://www.caffynonrivers.co.uk/_resources/cms/pdf/boats_on_our_rivers_again.pdf. Accessed on August 27, 2013.

"Chinook Salmon." *National Oceanic and Atmospheric Administration.* Northwest Regional Office, no date given. http://www.nwr.noaa.gov/protected_species/salmon_steelhead/salmon_and_steelhead_listings/chinook/chinook_salmon.html. Accessed September 1, 2013.

Columbia National Wildlife Refuge. U.S. Fish and Wildlife Service. U.S. Department of the Interior, no date given. http://www.fws.gov/columbia/wildlife.html. Accessed October 10, 2013.

"Columbia River Facts." *Office of Columbia River.* Department of Ecology State of Washington, no date given. http://www.ecy.wa.gov/programs/wr/cwp/cwpfactmap.html. Accessed November 16, 2013.

Correa, Nestor J., Andrew D. Carver, & Roberto Master. "Strengthening Partnerships for Effective Wildlife Rescue in the Panama Canal Expansion Area." *Human Dimensions of Wildlife* 13, no. 5 (September 2008): 382-384. http://web.ebscohost.com.ezproxy2.apus.edu/ehost/detail?vid=4&sid=176c6695-6aa5-4764-8e83-4931c3ec92f4%40sessionmgr111&hid=114&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=aph&AN=34506863. Accessed August 2, 2013.

Fagan, Brian. *Elixir: A History of Water and Humankind.* New York: Bloomsbury Press, 2011.

Fisher, Ron. "South America." *Builders of the Ancient World: Marvels of Engineering.* Washington, DC: National Geographic Society, 1986.

"French Canal Construction." *A History of the Panama Canal: French and American Construction Efforts.* Panama Canal Authority, no date given. http://www.pancanal.com/eng/history/history/. Accessed November 7, 2013.

Gollasch, Stephan, Bella Galil, and Andrew N. Cohen. *Bridging Divides: Maritime Canals as Invasion Corridors*. Dordrecht, The Netherlands: Springer, 2006.

Gorman, Brian. "National Academy of Sciences Salmon Study Reinforces Recovery Efforts Already Underway." *NOAA 95-R153*, 1995. *http://www.publicaffairs.noaa.gov/pr95/nov95/noaa95-r153.html*. Accessed September 5, 2013.

Greene, Julie. *The Canal Builders: Making America's Empire at the Panama Canal*. New York: Penguin Press, 2009.

Hadfield, Charles. *World Canals: Inland Navigation Past and Present*. New York: Facts on File, 1986.

"Hagerman Genetics Laboratory." *Fishery Science*. Columbia River Inter-Tribal Fish Commission, 2013. http://www.critfc.org/fish-and-watersheds/fishery-science/hagerman-genetics-laboratory/. Accessed November 14, 2013.

Hammond, Norman. "Mesoamerica." *Builders of the Ancient World: Marvels of Engineering:* Washington, DC: National Geographic Society, 1986.

Harrison, John. "Columbia Basin Project." *Columbia River History*. Northwest Power and Conversation Council, 2008. http://www.nwcouncil.org/history/ColumbiaBasinProject. Accessed October 5, 2013.

Harrison, John. "Grand Coulee Dam: Impacts on Fish." *Columbia River History*. Northwest Power and Conversation Council, 2010. http://www.nwcouncil.org/history/GrandCouleeImpactsOnFish. Accessed on October 13, 2013.

Hodge, A. Trevor. *Roman Aqueducts & Water Supply*. London: Gerald Duckworth & Co. Ltd., 1992.

Hritz, Carrie & McGuire Gibson. "Southern Mesopotamian Landscape as Input for a Model on Ancient Mesopotamia Society." *Oriental Institute:* University of Chicago, no date given. 1, 8, 9. http://oi.uchicago.edu/OI/PROJ/MASS/papers/SAA04_Hritz_Gibson_paper.pdf. Accessed on July 23, 2013.

"Hydroelectric Power Water Use." *The USGS Water Science School*. USGS: Science for a Changing World, no date given. http://ga.water.usgs.gov/edu/wuhy.html. Accessed November 9, 2013.

Kelsall, Ann Nottingham. "China." *Builders of the Ancient World: Marvels of Engineering*. Washington, DC: National Geographic Society, 1986.

Kramer, Samuel Noah. *Sumerians: Their History, Culture, and Character*. Chicago: The University of Chicago Press, 1963.

Kubba, Sam A.A., ed. *The Iraqi Marshlands and the Marsh Arabs: The Ma'dan, their Culture, and the Environment*. Reading, UK: Ithaca Press, 2011. http://site.ebrary.com/lib/apus/docDetail.action?docID=10457992. Accessed October 8, 2013.

Kwakkel, Erik. “Medieval Canals Spotted from Air.” *Alembic*. University of Victoria, 2008. http://web.uvic.ca/medieval/downloads/alembic1-3.pdf. Accessed August 10, 2013.

“Lake Roosevelt.” *The Story of the Columbia Basin Project*. U.S. Department of the Interior: Bureau of Reclamation, 1964 (updated 2008). http://www.nps.gov/history/history/online_books/dams/columbia_basin/sec2.htm. Accessed August 30, 2013.

“Lake Roosevelt National Recreation Area.” *National Park Service*. U.S. Department of the Interior, no date given. http://www.nps.gov/laro/index.htm. Accessed November 3, 2013.

Leigh, E. G. *Tropical Forest Ecology: A View from Barro Colorado Island*. New York: Oxford University Press, 1999.

Maasakkers, Tijs van. *The Role of Science in Water Management in Washington State*. Massachusetts Institute of Technology, 2008. http://web.mit.edu/dusp/epp/music/pdf/tijsfirstyearpaper.pdf. Accessed November 2, 2013.

McNeill, William H. *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000*. Chicago: Basil Blackwell Publisher Limited, 1982.

Moreno, Stanley Heckado. "Impact of Development on the Panama Canal Environment." *Journal Of Interamerican Studies & World Affairs* 35, no. 3, 1993: 129. *Business Source Complete*. http://web.ebscohost.com.ezproxy1.apus.edu/ehost/detail?vid=7&sid=adb4b2cd-9ab2-48a9-865b-c8bcfa63e58e%40sessionmgr4003&hid=4101&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=bth&AN=9403030829. Accessed October 3, 2013.

Netboy, Anthony. *The Columbia River Salmon and Steelhead Trout: Their Fight for Survival.* Seattle: University of Washington Press, 1980.

Nowak, Kenneth C. *Stochastic Streamflow Simulation at Interdecadal Time Scales and Implication to Water Resources Management in the Colorado River Basin*, 2011. http://cadswes.colorado.edu/sites/default/files/PDF/Theses-PhD/Nowak-PhD.pdf. Accessed November 16, 2013.

“Panama Announces Canal Expansion.” *Oil Spill Intelligence Report* 20, no. 18 (April 27, 2006): 1-2. http://web.ebscohost.com.ezproxy1.apus.edu/ehost/pdfviewer/pdfviewer?vid=15&sid=36b9f4c8-f764-4145-a3a0-0fa4146d8f39%40sessionmgr13&hid=18. Accessed August 2, 2013.

Petroski, Henry. *The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems.* New York: Random House, Inc., 2011.

Petroski, Henry. *Remaking the World: Adventures in Engineering.* New York: Alfred A. Knopf, Inc., 1997.

Pillsbury, Arthur F. "The Salinity of Rivers." *Scientific American.* 245(1):54-65, 1981. http://www.sci.sdsu.edu/salton/TheSalinityofRivers.html Accessed October 12, 2013.

Pitzer, Paul C. *Grand Coulee: Harnessing a Dream.* Pullman, WA: Washington State University Press, 1994.

Ransom, P.J.G. *The Archaeology of Canals.* Tadworth, England: World's Work, 1979.

"Sanitation and Infrastructure." *Army Engineers and the Building of the Panama Canal, 1907-1914.* http://www.armyengineer.com/history/panama/projects/Sanitation/Sanitation.html. Accessed November 8, 2013.

Sherratt, Andrew. *The Cambridge Encyclopedia of Archaeology.* New York: Cambridge University Press, 1980.

Solomon, Steven. *Water: The Epic Struggle for Wealth, Power, and Civilization.* New York: HarperCollins Publishers, 2010.

Tucker, R. P. *Insatiable Appetite: The United States and the Ecological Degradation of the Tropical World*. Berkeley, CA: University of California Press, 2000. http://site.ebrary.com/lib/apus/docDetail.action?docID=10054460 Accessed September 8, 2013.

Ungo, Ricardo, et.al. "Risk Planning and Management for the Panama Canal Expansion Program." *Journal of Construction Engineering & Management* 137, no. 10 (October 2011): 762-771. http://web.ebscohost.com.ezproxy1.apus.edu/ehost/pdfviewer/pdfviewer?vid=6&sid=92e363fb-fcbf-4a1f-a6fc-dfd9cfe1866e%40sessionmgr4&hid=24 . Accessed July 31, 2013.

"Water Properties: Dissolved Oxygen." *The USGS Water Science School.* USGS: Science for a Changing World, no date given. http://ga.water.usgs.gov/edu/dissolvedoxygen.html. Accessed October 27, 2013.