Irrigation Management

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Importance of Irrigation

- Agriculture is either rainfed or is dependent on irrigation.
- It is greatly impacted by the vagaries of nature, especially weather.
- Rainfall varies from place to place for a given month or year and from month (or year) to month (or year) for a given place.
- Irrigation is needed for productive agriculture, because rainfall is seldom adequate and timely for meeting agricultural needs, even in humid areas.
- For productive agriculture and consequent food security, irrigation is vital.

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Importance of Irrigation (Contd.)

- Non-agricultural lands, such as wastelands, can be brought under agriculture by irrigation.
- Irrigation also serves a source of recharge.
- It mitigates meteorological drought.
- It allows more than one crop a year.
- It helps cultivation of different crops.
- It helps sustain the ecosystem.
- It is critical for food as well as nutritional security, especially in semi-arid and arid areas.

Definition of Irrigation

- Irrigation is defined as an artificial application of water to plants for overcoming the lack, insufficiency, or poor distribution of rainfall.
- It is the controlled application of water to croplands, with the primary objective of creating an optimal soil moisture regime for maximizing crop production and quality, and at the same time minimizing environmental degradation inherent in irrigation of agricultural lands.

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Purpose of Irrigation

- The purpose of irrigation is to provide water to crops where and when crop water requirements cannot be met by natural rainfall.

- In many areas there is deficit rainfall and in some areas rainfall is not enough during the crop growing season and in other areas there is hardly any rainfall.

- Many areas without or with little rainfall are wastelands, but they can be transformed into crop producing areas by irrigation.

Factors Impacting Irrigation

- However, irrigation requirement is fundamentally impacted by climate, soil, and crops to be irrigated.
- It is also impacted by the source, availability, and quality of water.
- Providing a snapshot of irrigation worldwide as well as in the United States, the discussion reflects on the future of irrigation.

Variability of Precipitation

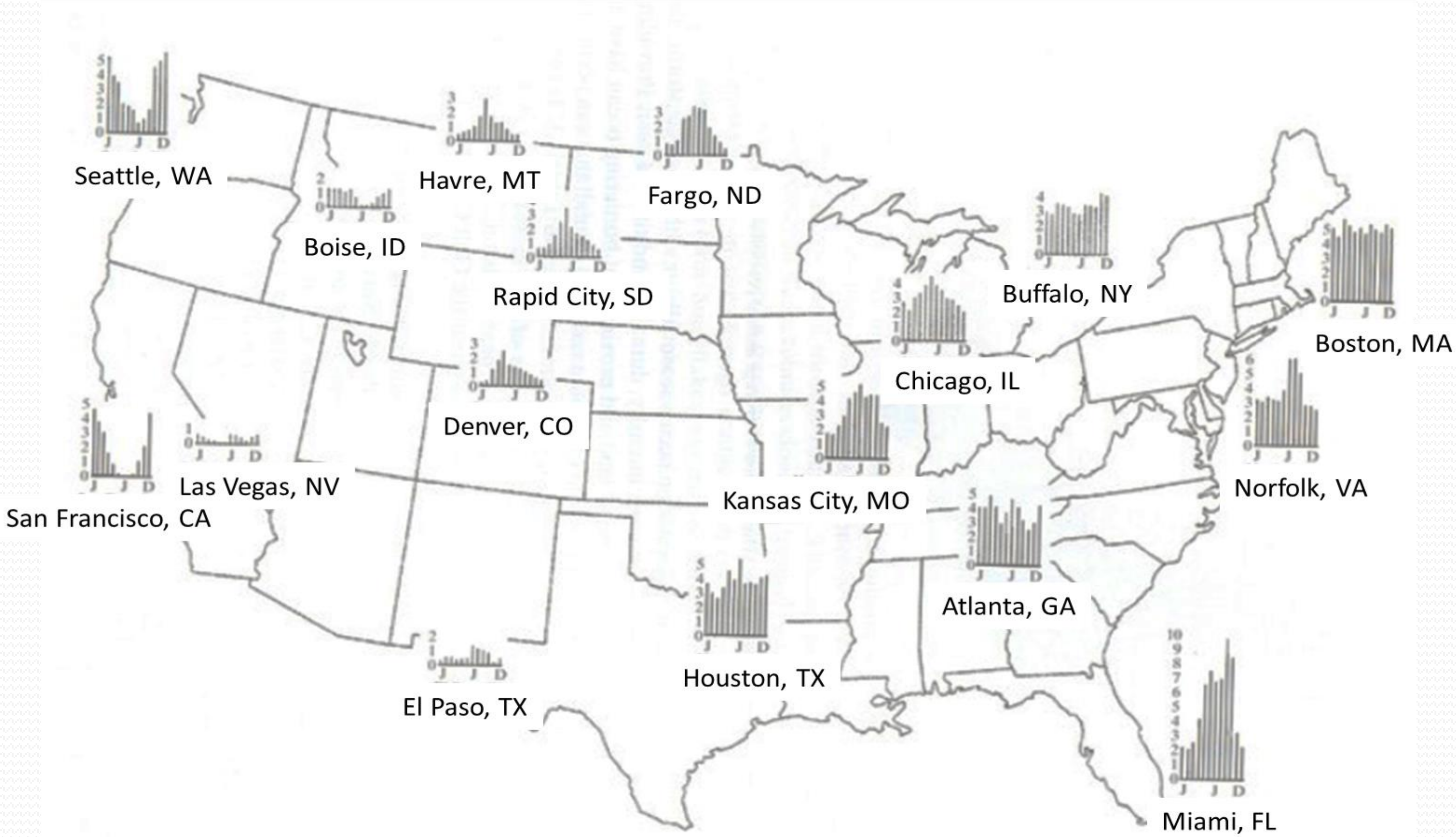

Figure 1. Average monthly precipitation distribution across the United States (U.S. Environmental Data Service, 2013)

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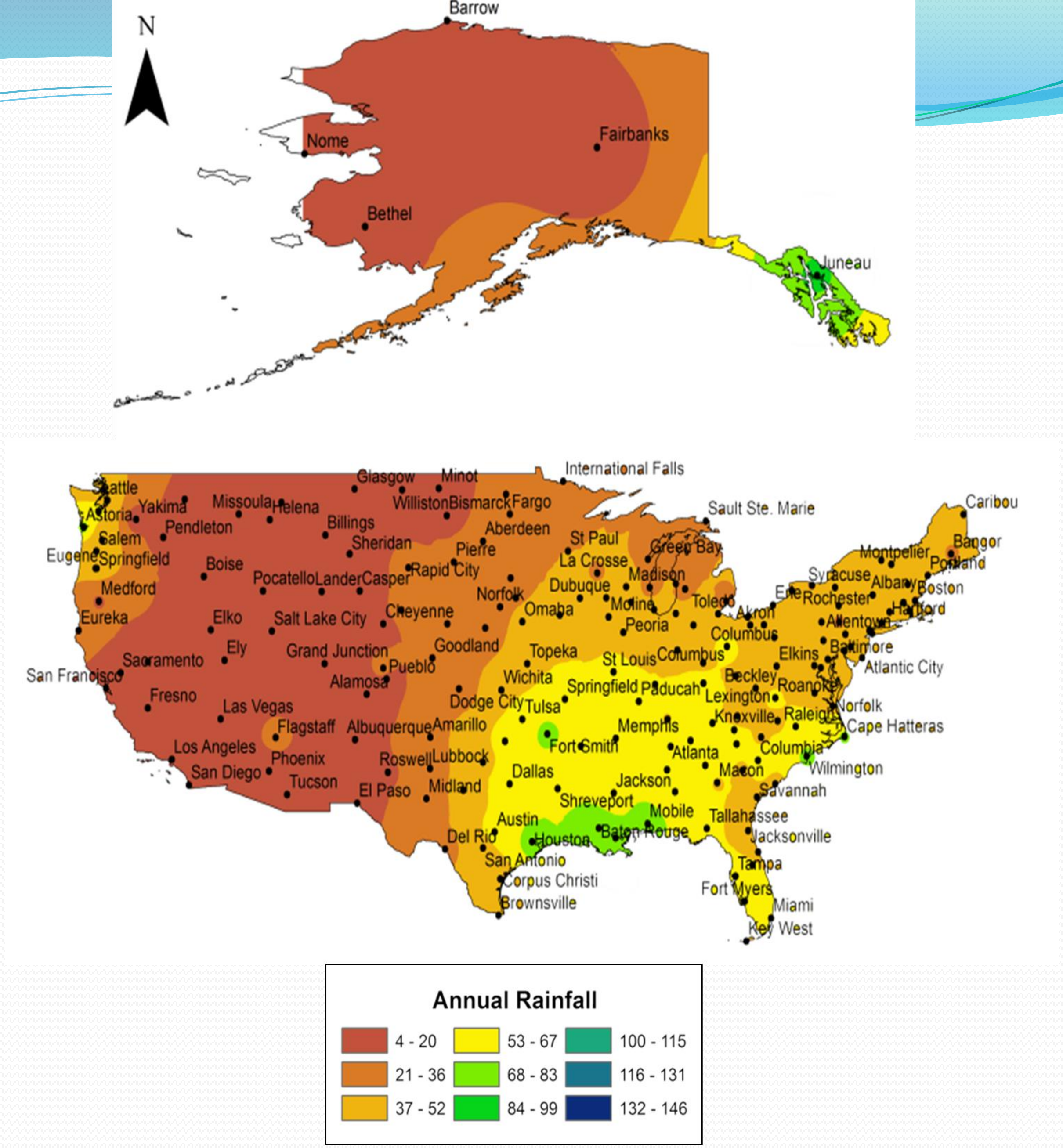

Figure 2. Annual Precipitation in 2015 across the United States (https://www.ncdc.noaa.gov/sotc/national/201501)

Variability of Precipitation (Contd.)

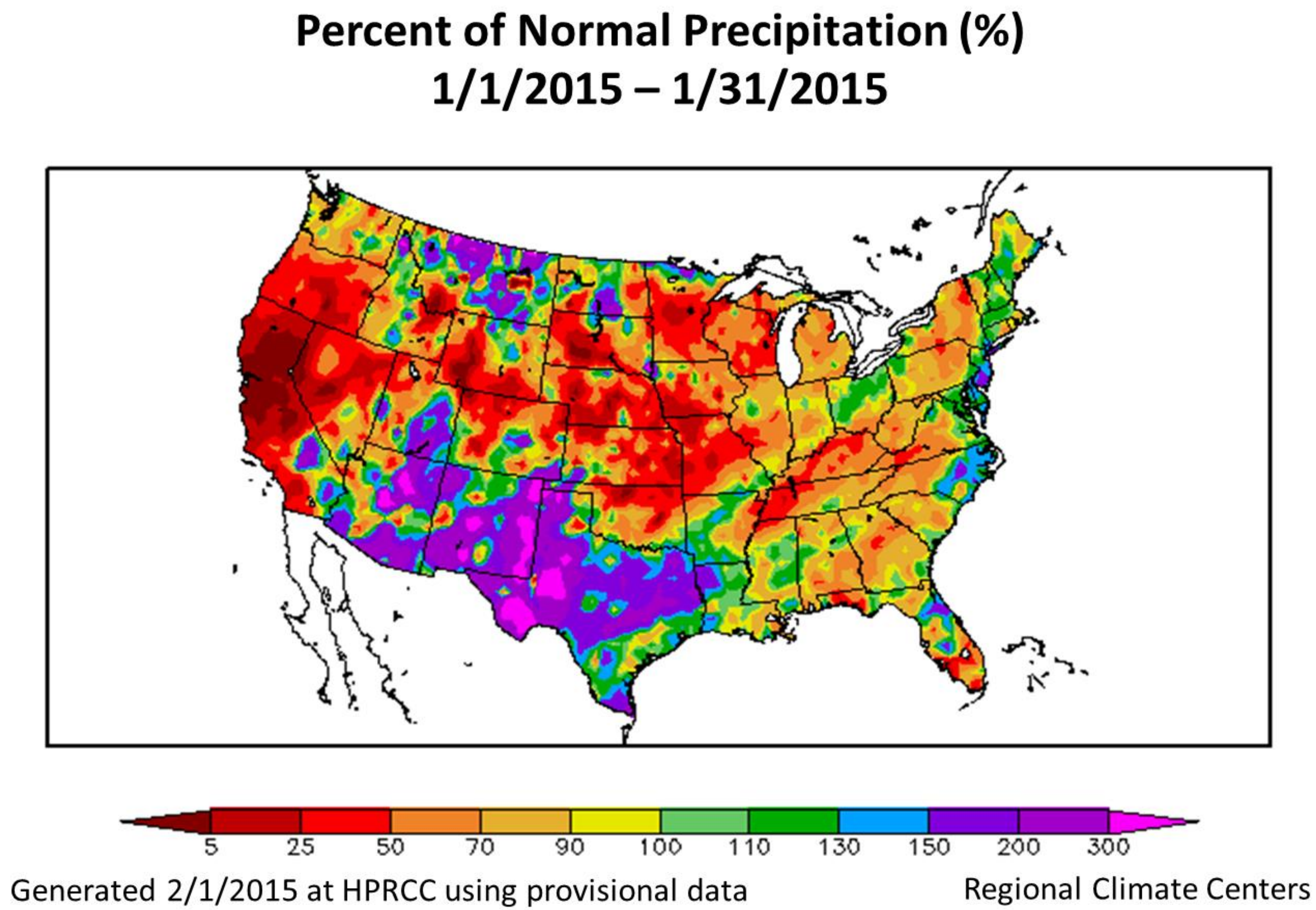

Figure 3. Increase in the normal precipitation in 2015 across the United States (https://www.ncdc.noaa.gov/sotc/national/201501)

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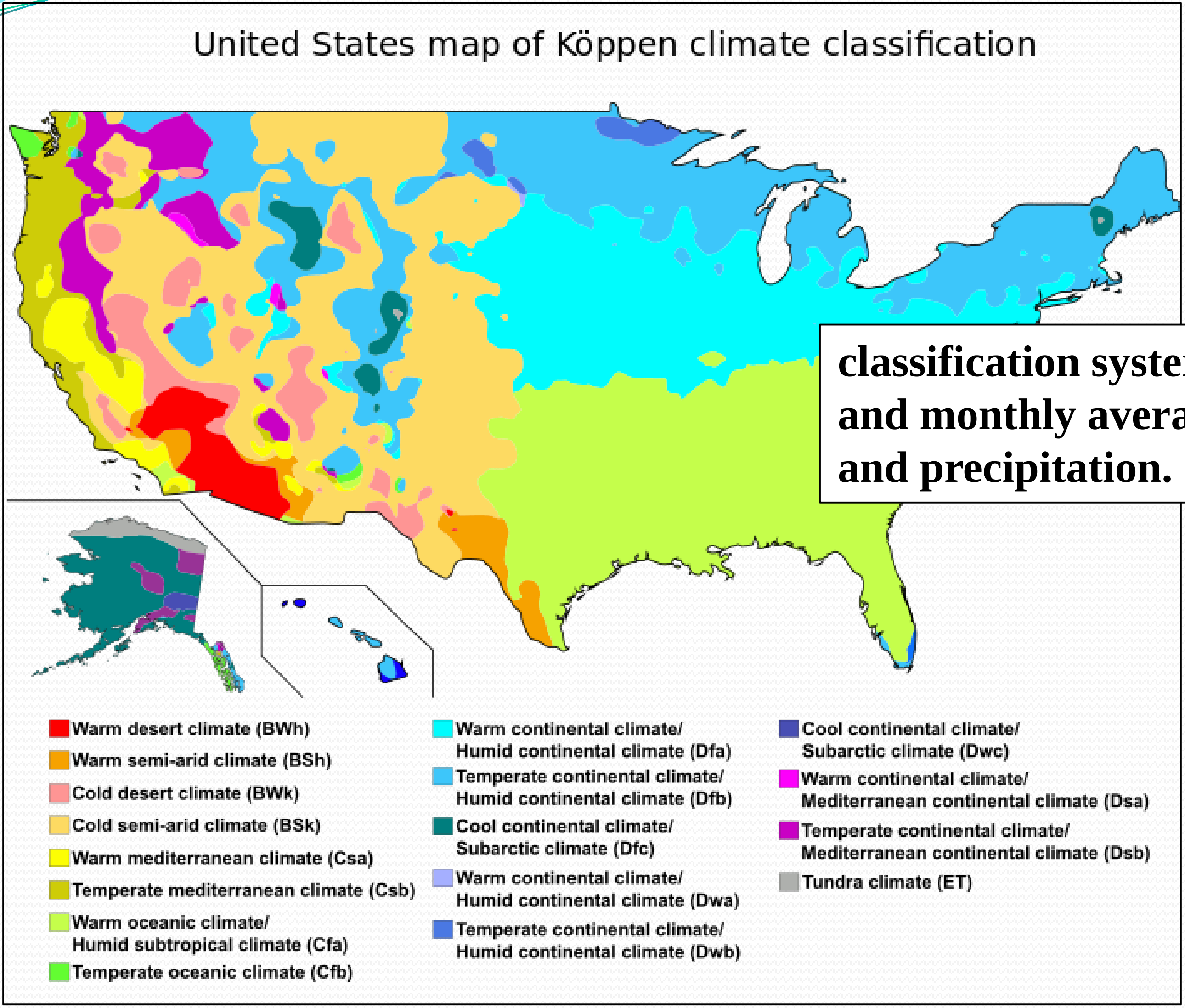
Variability of Pecipitation (Contd.)



classification system based upon the annual and monthly averages of temperature and precipitation.

Figure 4. Köppen climate classification for the United States (https://en.wikipedia.org/wiki/Humid_subtropical_climate)

Benefits of irrigation

- Transformation of unproductive areas to agricultural production areas.
- Increased productivity.
- Production guarantee → water deficit
- Harvesting in the off-season
- Allowing more than one harvest per year
- Best production quality
- Job creation

Benefits of irrigation (Contd.)

Table 1. Increase in yield due to irrigation

Crop	Not irrigated (kg/ha)	Irrigated Kg/ha	Yield increment (%)
Cotton	848	2,700	218
Rice	1,739	3,750	115
beans	388	2,300	492
corn	1,985	5,500	177
Soybean	1,844	3,000	62
oat	1,668	3,400	104

Table 2. Average yields of non-irrigated crops in comparison with irrigated crops (NGWI= not grown without irrigatipon, NP= not publsihed, bu.=bushels, and bo.=boxes)

Crops, State gown in and year	Yield per acre		
	Non-irrigated	Irrigated	Increase
Alfalfa			
North Dakota (1966)	2.0 tons	4.4 tons	2.4 tons
South Dakota (1966)	2.5 tons	5.3 tons	2.8 tons
Cabbage			
New Jersey (1955-59)	12.5 tons	18.9 tons	6.4 tons
Corn			
Florida (1971)	115 bu.	190 bu.	75 bu.
Nebraska (1966)	36 bu.	102 bu.	66 bu.
North Carolina (1963-68)	101.0	139 bu.	38 bu.
North Dakota (1966)	44.0	77.9 bu.	33.9 bu.
South Dakota (1949-55)	32.0	92.0 bu.	60 bu.
Virginia (1954-55)	83.3	109.2 bu.	28.9 bu.
Cotton (lint and seed)			
Arizona (1964-65)	NGWI	2137 lbs.	2137 lbs.
Arkansas (1950-52)	1608 bu.	2083 lbs.	475 lbs.
Georgia (1949-53)	1216 bu.	1902 lbs.	686 lbs.
Missouri (1953)	1414 bu.	2683 lbs.	1269 lbs.
North Carolina (1963-67)	1836 bu.	1932 lbs.	96 lbs.
South Carolina (1954-55)	1077 bu.	1668 lbs.	591 lbs.
Field beans (edible)			
Nebraska (1956)	27 bu.	54 bu.	27 bu.
Grain Sorghum			
Arizona (1964-65)	NGWI	72 bu.	72 bu.
Nebraska (1966)	39 bu.	87 bu.	48 bu.
Oklahoma (1958-62)	9.3 bu.	44.4 bu.	35.1 bu.
Grapefruit			
Florida (1960-67)	735 bu.	1056 bo.	321 bo.
Oranges			
Florida (19600-67)	369 bo.	493 bo	124 bo.
Peanuts			
North Carolina (1963-68)	2632 lbs.	3168 lbs.	536 lbs.
Oklahoma (1956-59)	1014 lbs.	2306 lbs.	1292 lbs.
Peaches			
Maryland (1955-64)	300 lbs.	372 lbs.	72 lbs.

Crops, State gown in and year	Yield per acre		
	Non-irrigated	Irrigated	Increase
Pole beans			
Georgia (1950)	2583 lbs.	6025 lbs.	3442 lbs.
Potatoes (Irish)			
Arizona (1964-65)	NGWI	6.5 tons	6.5 tons
California (1968)	350 sacks	450 sacks	100 sacks
New York (1946)	NP	NP	57 bu.
Texas	1.5 tons	7.0 tons	5.5 tons
Wisconsin (1946)	NP	NP	100 bu.
Silage			
Alabama (1966-68)	31 tons	47 tons	16 tons
Soybeans			
Arkansas (1966-68)	28.9 bu.	37.2 bu.	8.3 bu.
Georgia (1978)	30 bu.	53 bu.	23 bu.
Missouri (1959)	NP	NP	8.0 bu.
Sugar Beats			
Arizona (1964-85)	NGWI	20.5 tons	20.5 tons
North Dakota (1949-52)	NGWI	20 tons	20 tons
Wyoming (1956)	NGWI	16 tons	25.0 tons
Sweet Corn			
New Jersey (1955-58)	5600 lbs.	11,900 lbs.	6,300 lbs.
Sweet Potatoes			
Louisiana (1953-56)	117.9 bu.	271.9 bu.	154 bu.
Tobacco			
South Carolina (1951-54)	1183 lbs.	1547 lbs.	364 lbs.
Virginia (1954-57)	2699 lbs.	3042 lbs.	343 lbs.
Tomatoes			
Georgia (1947-53)	17430 lbs.	23485 lbs.	6055 lbs.
Wheat			
Kansas (1954-59)	21 bu.	48.6 bu.	27.6 bu.
Oklahoma (1954)	13 bu.	34 bu.	21.0 bu.
Texas (1966-67)	15.8 bu.	53.8 bu.	38 bu.

Limitations of Irrigation

- High consumption of water→irrigation management
- High implementation costs
- Lack of hand specialized labor
- Salinization of soils managed inadequately
- Environmental impacts→ Waste, mosquitoes,
  - change in ecosystems
- Soil water availability

Need for Irrigation

- The demand for food is increasing each year because of rising population, growing food requirements, and increasing standard of living.

- Further, a lot of food grains and other agriculture produce are wasted during harvesting, transportation, distribution, storage, and consumption, as shown in Figure 1.7.

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Need for Irrigation (Contd.)

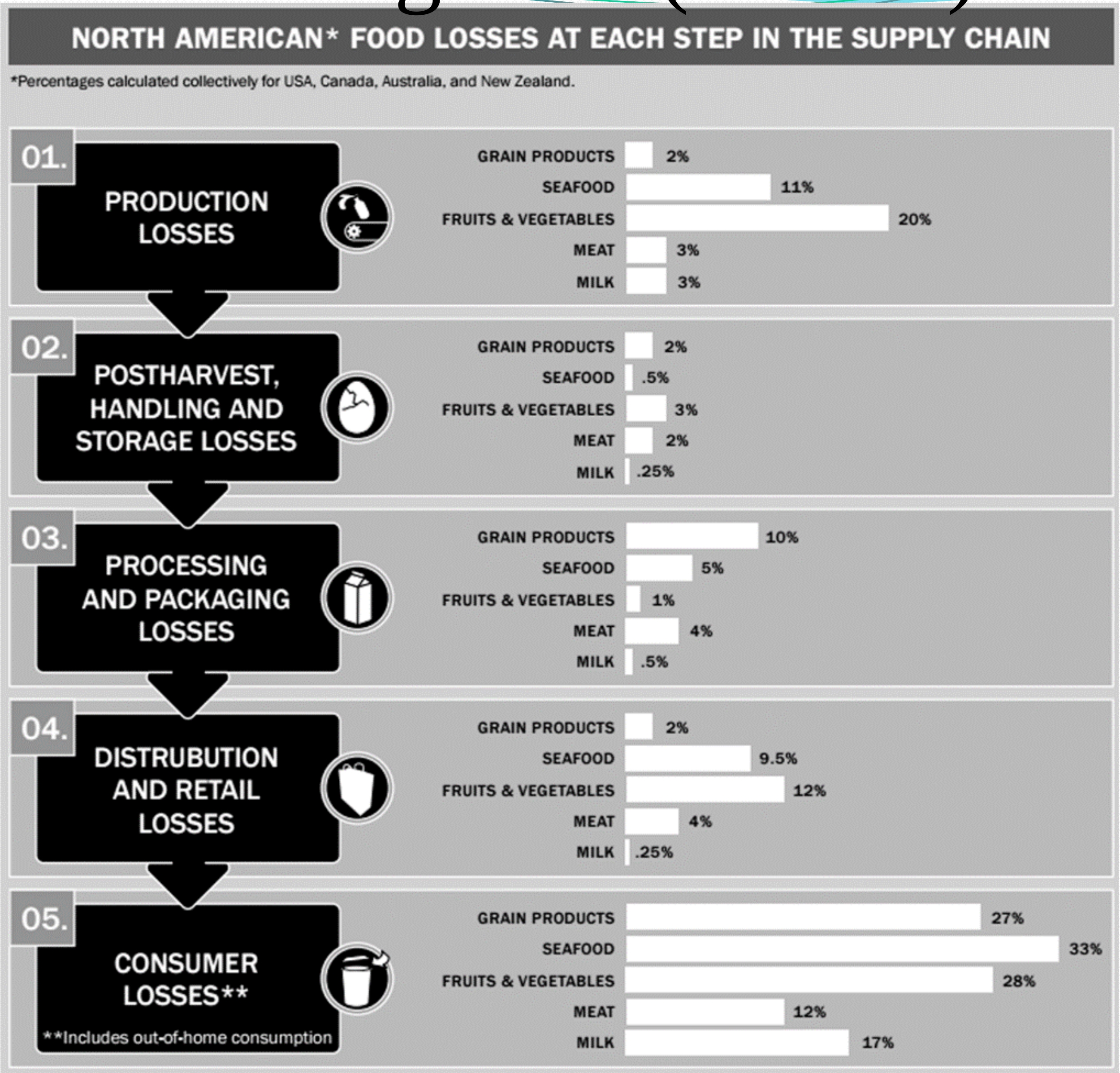

Figure 1.7 Food losses in North American given by the FAO 2011 (https://www.nrdc.org/sites/default/files/wasted-food-IP.pdf)

Need for Irrigation (Contd.)

- The per capita food loss in Europe and North-America is 280-300 kg/year.

- In sub Saharan-Africa and South/Southeast Asia it is 120-170 kg/year (FAO, 2011).

- This means that more food will have to be produced to ensure food security.

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Need for Irrigation (Contd.)

- In the next 35-45 years, world food production will have to be doubled in order to meet the demands of increased population.

- It may be noted that 90% of this increased food production will have to come from existing lands and 70% of this increased food production will have to come from irrigated lands.

Need for Irrigation (Contd.)

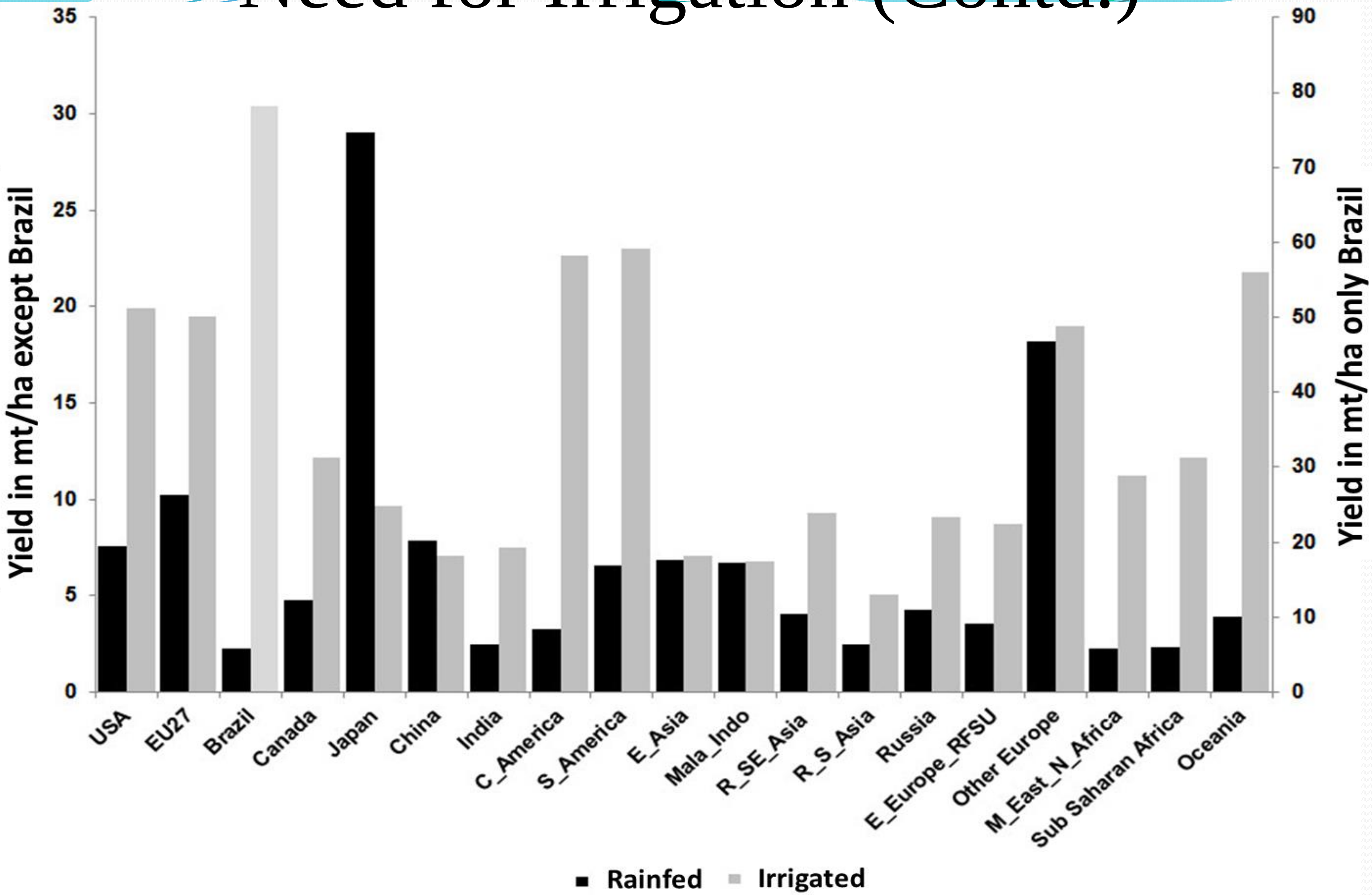

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Figure 8. Different countries irrigated and rainfed agricultural lands and their production (from Taheripour et al., 2013)

Need for Irrigation (Contd.)

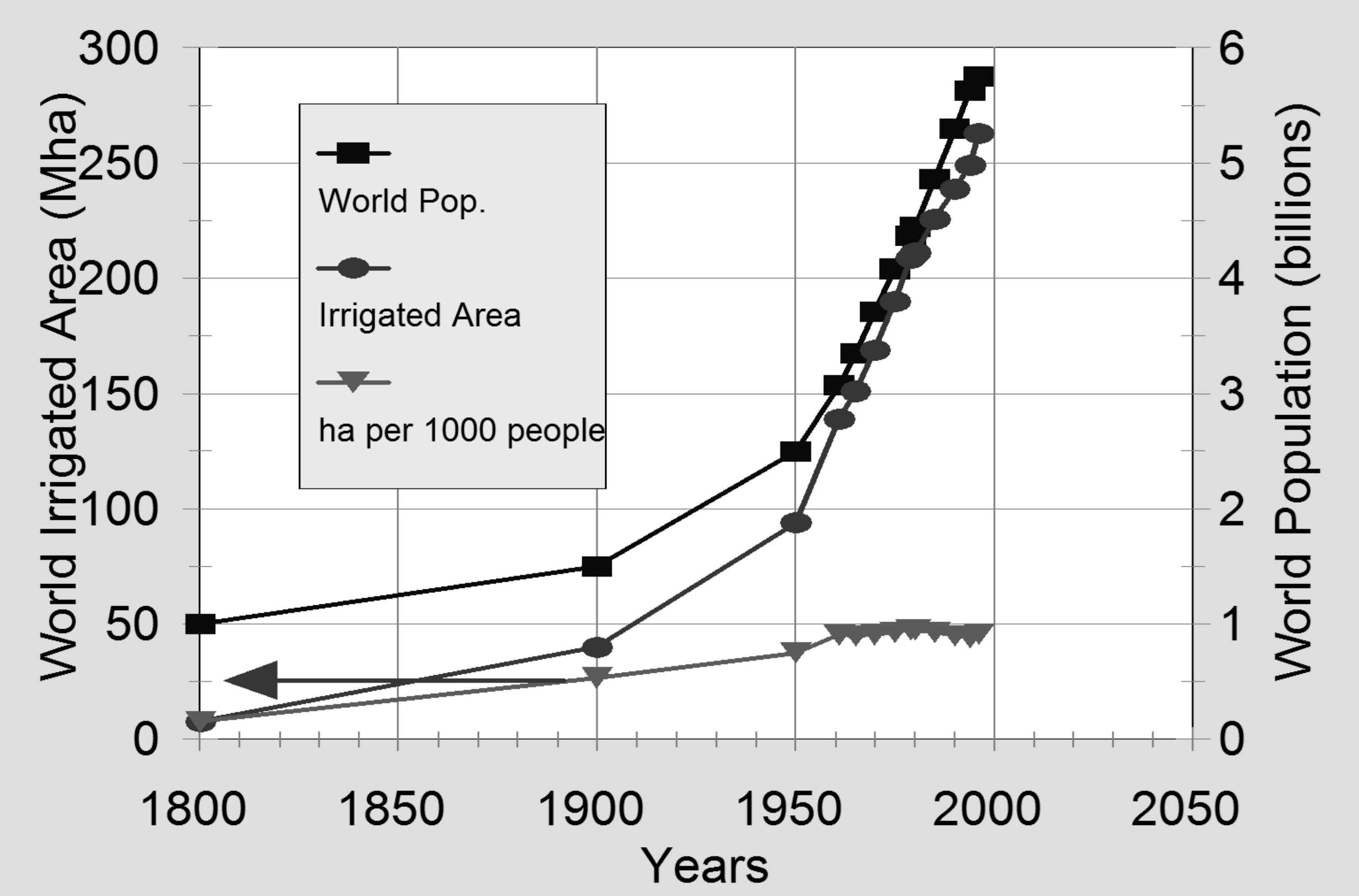

Figure 9. World polulation, world irrigated area, and hecatre per one thousand people (from Howell, 2006).

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Need for Irrigation (Contd.)

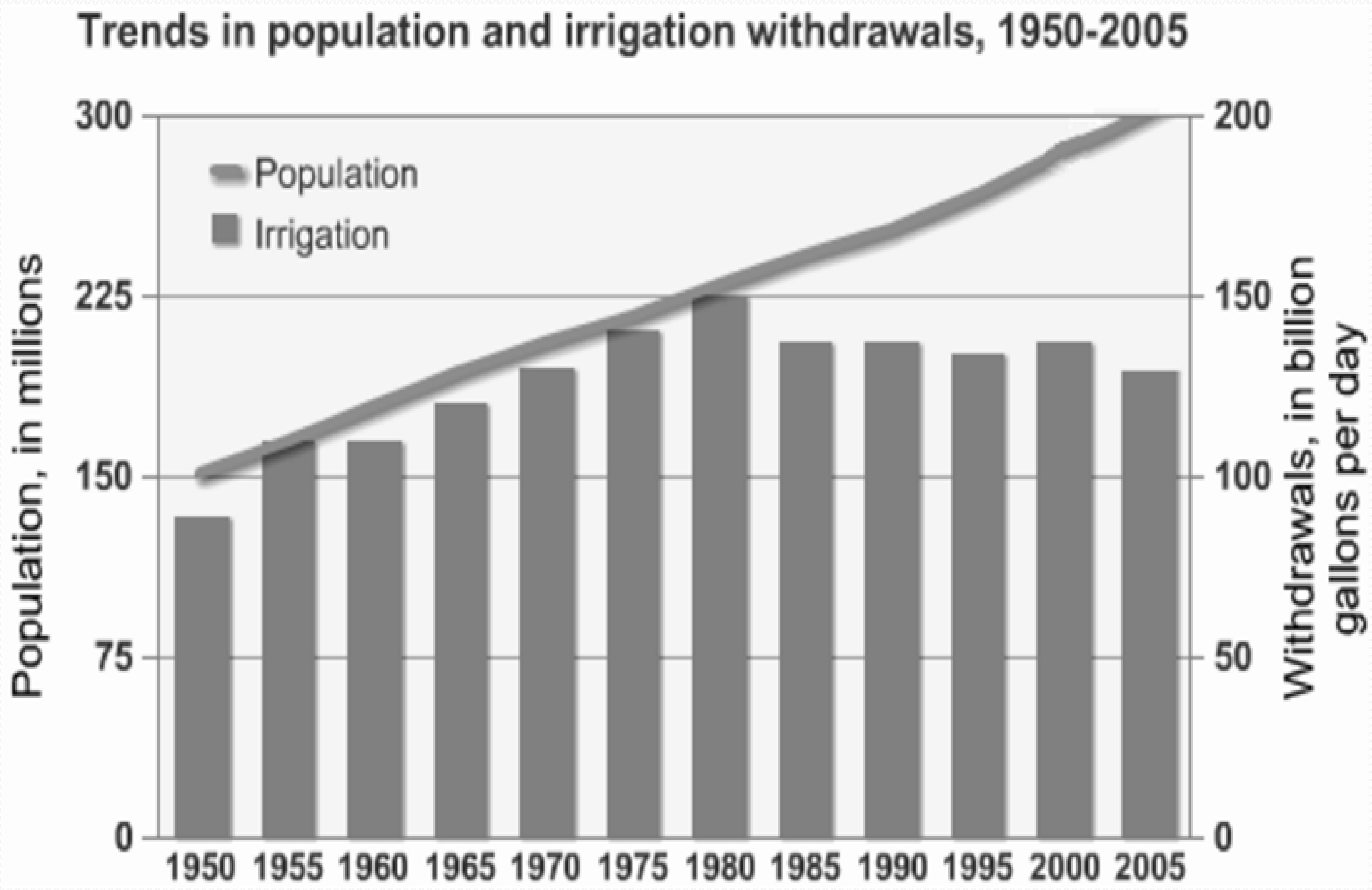

Figure 10. Trend of irrigation withdrawals with increasing population in the United States (http://water.usgs.gov/edu/wuir.html)

Food Security

- **1. Population and Growth Pattern**
- **2. Food Requirement**
- **3. Rising Living Standard**
- **4. Nutritional Security**

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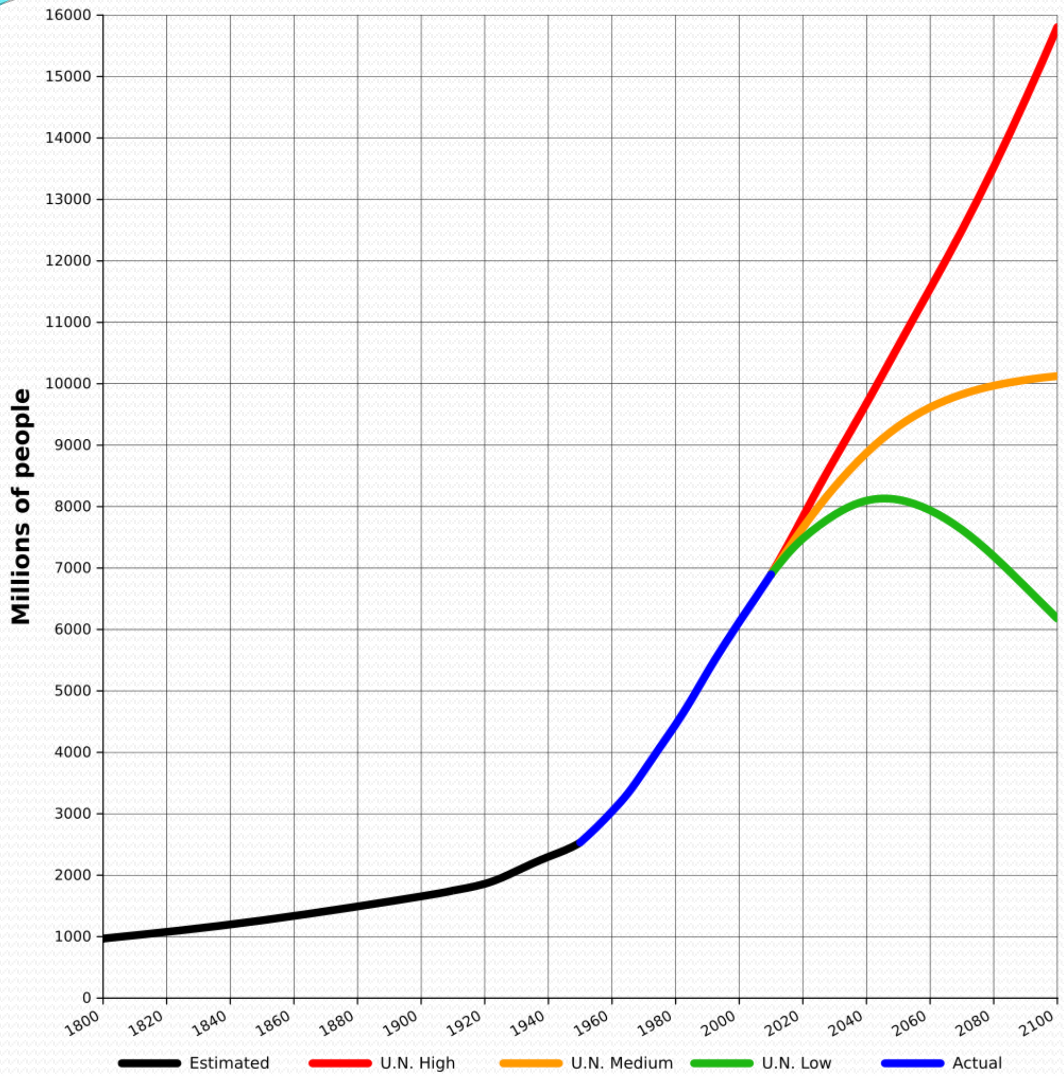
Population and Growth Pattern

- The world population exceeded 6 billion in 2000 and it is projected to exceed 9 billion by 2050 and 10 billion by the turn of 2100 (United Nations, 2011).
- As the world's population has increased since the 1960s, irrigated land area has also increased. The area per capita irrigated land remained relatively stable over time.

Table 3. Population pressure on the top water-scare areas of the world (http://pai.org/wp-content/uploads/2012/04/PAI-1293-WATER-4PG.pdf)

Country	Population 2010 (Thousands)	Projected Population 2035 (Thousands)	Per capita water availability 2035 (m^3/person/yr)
Kuwait	2737	4328	4.6
United Arab Emirates	7512	11042	13.6
Qatar	1759	2451	21.6
The Bahamas	343	426	46.9
Saudi Arabia	27448	40444	59.3
Bahrain	1262	1711	67.8
Libya	6355	8081	74.3
Maldives	316	392	76.6
Yemen	24053	46196	88.8
Singapore	5086	6098	98.4

Population and Growth Pattern (Contd.)



Population growth as a function of time [World population estimates from 1800 to 2100, based on "high", "medium" and "low" United Nations projections in 2010 (colored red, orange and green) and US Census Bureau historical estimates (in black). Actual recorded population figures are colored in blue. According to the highest estimate, the world population may rise to 16 billion by 2100; according to the lowest estimate, it may decline to 6 billion [From Wikipedia, the free encyclopedia].

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Food Requirement

- In terms of calories the United States Department of Agriculture estimates that most women need 1,600 to 2,400 calories, while the majority of men need 2,000 to 3,000 calories each day to maintain a healthy weight.
- To produce enough food to satisfy the global food requirement, a huge amount of water is needed.

Table 4.: Per capita food consumption (kcal/person/day) across the world (http://www.fao.org/docrep/005/ac911e/ac911e05.htm)

Region	1964 - 1966	1974 - 1976	1984 - 1986	1997 - 1999	2015	2030
World	2358	2435	2655	2803	2940	3050
Developing countries	2054	2152	2450	2681	2850	2980
Near East and North Africa	2290	2591	2953	3006	3090	3170
Sub-Saharan Africa[a]	2058	2079	2057	2195	2360	2540
Latin America and the Caribbean	2393	2546	2689	2824	2980	3140
East Asia	1957	2105	2559	2921	3060	3190
South Asia	2017	1986	2205	2403	2700	2900
Industrialized countries	2947	3065	3206	3380	3440	3500
Transition countries	3222	3385	3379	2906	3060	3180

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Food Requirement (Contd.)

- The food consumption has changed significantly over the past 100 years, as shown in Figure 1.12.
- These days, people eat more and waste more. To produce enough food to satisfy the global food requirement, a huge amount of water is needed. For example, to produce one ton of grain requires nearly 1,000 m^3 of water.

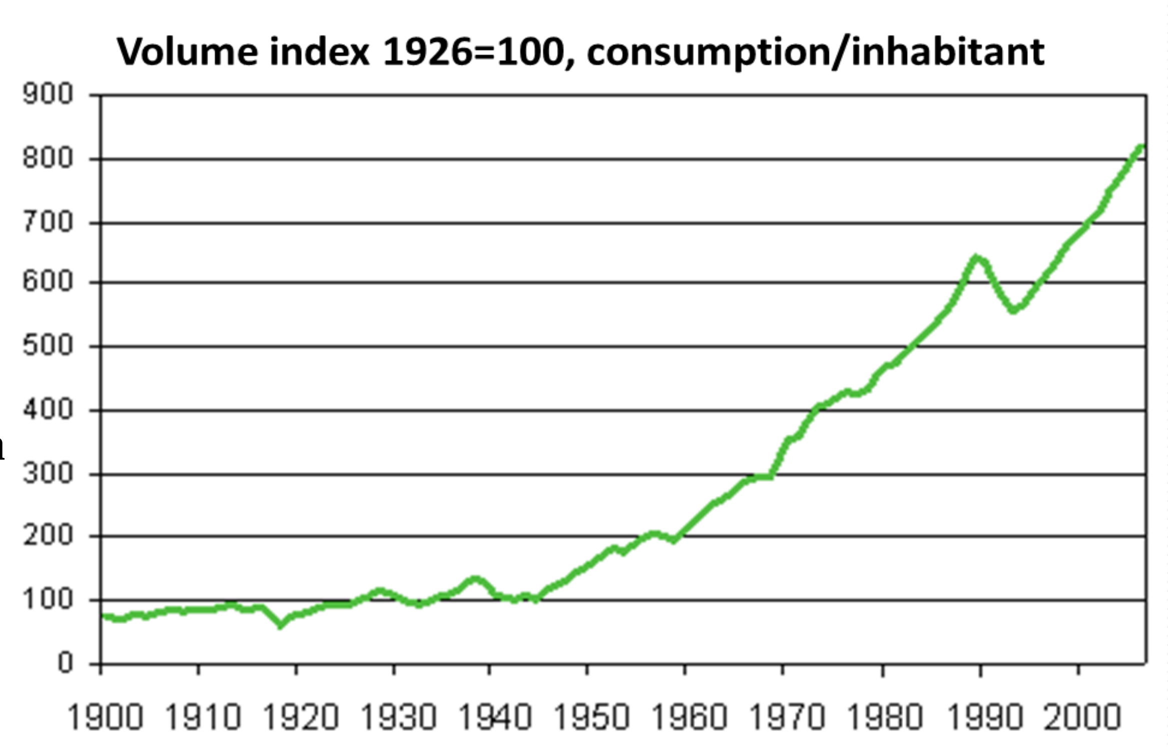

Figure 12.. Food consumption as a function of time (after USDA, 2010).

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Food Requirement (Contd.)

- Much more water is needed to produce livestock products, as for example, about 15,500 m^3 of water is needed to produce 1 ton of beef, as shown in Table 1.5.

Table 5. Water requirements: Typical values for the volume of water required to produce common foodstuffs (source: www.theguardian.com/news/datablog/2013/jan/10/how-much-water-food-production-waste)

Food	Quantity	Water consumption, liters	Food	Quantity	Water consumption, liters
Chocolate	1 kg	17,196	Pizza	1 unit	1,239
Beef	1 kg	15,415	Apple	1 kg	822
Sheep Meat	1 kg	10,412	Banana	1 kg	790
Pork	1 kg	5,988	Potatoes	1 kg	287
Butter	1 kg	5,553	Milk	250ml	255
Chicken	1 kg	4,325	Cabbage	1 kg	237
Cheese	1 kg	3,178	Tomato	1 kg	214
Olives	1 kg	3,025	Egg	1 ea	196
Rice	1 kg	2,497	Wine	250ml	109
Cotton	250g	2,495	Beer	250ml	74
Bread	1 kg	1,608	Tea	250 ml	27

Food Requirement (Contd.)

- There is a large variation in water footprint of various items of food and beverages, as illustrated in Figure 1.13.

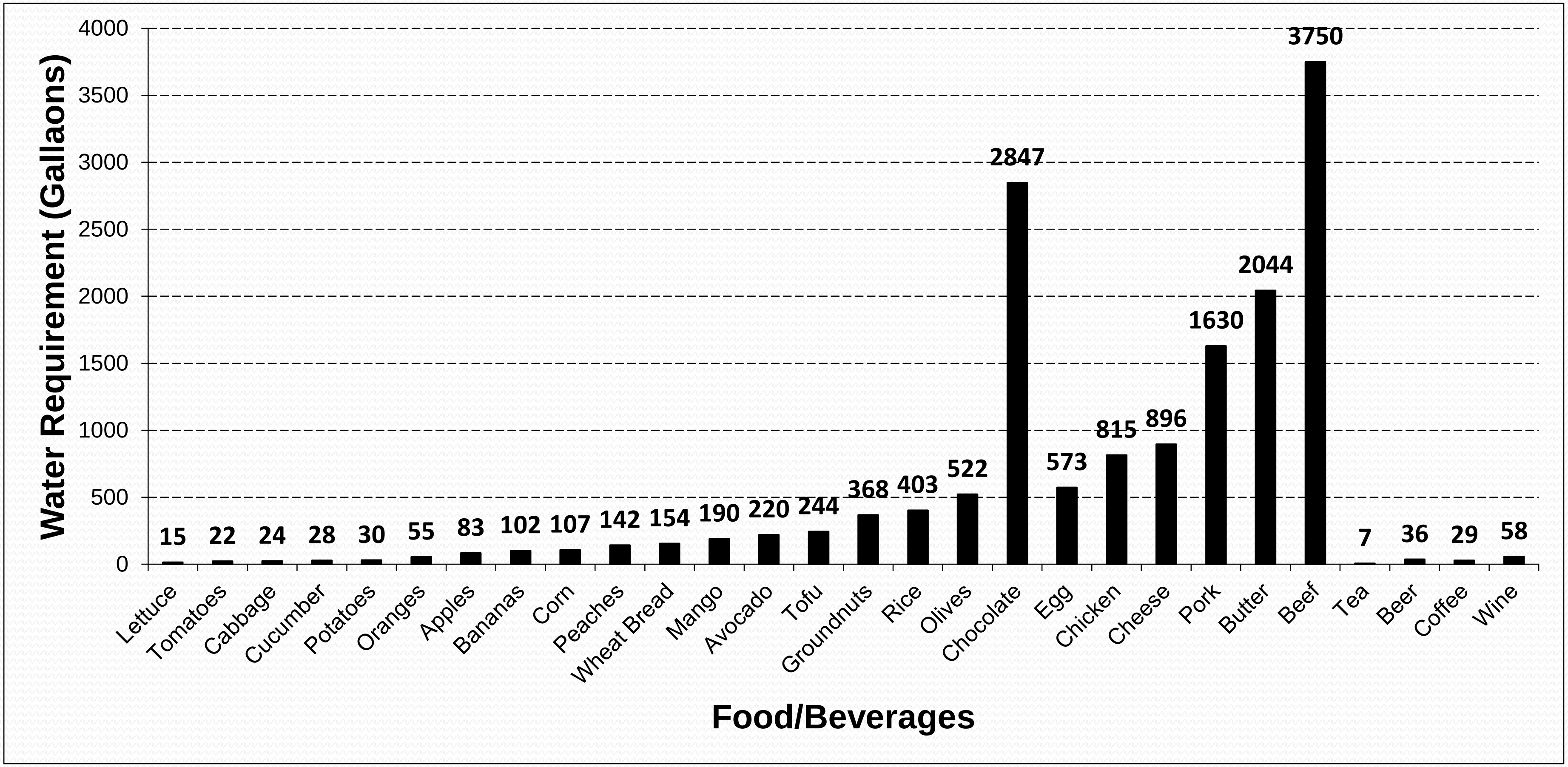

Figure 13. Water footprint of various food/beverages items (http://www.treehugger.com/green-food/from-lettuce-to-beef-whats-the-water-footprint-of-your-food.html)

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Food Requirement (Contd.)

- Nearly a billion people, approximately one in six people globally, do not have access to adequate food at present.
  - In **India** alone, nearly 195 million people are malnourished-about 25% of global malnourished population.
  - **China** has about 134 million malnourished people. Malnourishment is caused by poverty, inadequate supply chains, rampant food wastage, and poor farming.

- To ensure food security requires good agricultural and management practices, advances in irrigation and technology, proper policies, and strong political will (Brabeck-Letmathe and Biswas, 2015: Source: http://bit.ly/1MS2tWW).

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Rising Living Standard

- The usual connotation of living standard has to do with the quality of life which is measured by a number of factors, including income, housing, health care, education, environmental quality, infrastructure, freedoms, etc.

- There has been a substantial rise in the standard of living for the past fifty years and this has translated into greater food and fiber requirement.

Rising Living Standard (Contd.)

- Associated with this rise in the standard of living in rapidly developing economies is a steady increase in the demand for meat products and meat consumption.

- In China, meat consumption rose from 20 kg/capita in 1995 to 50 kg/capita in 2009, increasing pressure on livestock production and water withdrawals.

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Rising Living Standard (Contd.)

- Consumption by an American is higher than the consumption by eight Haitians (as shown in Table 1.6).

Table 6. Meat consumption (MC) measured in lbs./person/year
(Source: https://vegetarian.procon.org/view.resource.php?resourceID=004716)

Rank	Country	MC	Rank	Country	MC
1	Luxembourg	314.6	115	Mali	49.4
2	Hong Kong	295.9	116	Egypt	49.2
3	**United States**	**279.1**	117	Sudan	48.5
4	Australia	259.3	118	Bosnia and Herzgovina	47.8
5	Austria	240.5	119	Algeria	47.6
6	Spain	237.9	120	Turkey	46.7
7	Cyprus	230.16	121	Congo	46.3
8	New Zealand	229.3	122	Djibouti	46.1
9	Denmark	222	123	Nicaragua	44.8
10	Ireland	222	124	Syria	43
11	Israel	219.8	125	Azerbaijan	42.8
12	Bahamas	217.8	:	:	:
13	Macao	214.3	:	:	:
14	**Canada**	**212.3**	:	:	:
:	:	:	:	:	:
:	:	:	**137**	**Haiti**	**31.1**
30	**Brazil**	**178.1**	138	Sao Tome and Principe	30.2
31	Greece	174.6	139	Afghanistan	30
32	Antigua and Barbuda	173.7	140	Cameroon	29.8
33	Taiwan	173.5	141	Zambia	29.5
34	Netherlands	171.5	142	Cote d'Ivoire	28.7

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Nutritional Security

- Lack of food security is not the main or even the sole cause of malnutrition or lack of nutritional security.
- Many developing countries produce enough food to combat hunger but a significant proportion of their population suffers from the lack of nutritional security which encompasses malnutrition and obesity.

- This may partly be because of the lack of understanding of nutritional security, male domination resulting in gender discrimination, social taboos, lack of proper health education, corruption, and national pride.

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Nutritional Security (Contd.)

- Nearly 3.1 million children under the age of five die each year because of malnutrition, accounting for about 45% of child mortality.

- About two thirds of the world's malnourished people live in Asia and about one in four people living in Sub-Saharan Africa is malnourished.

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Nutritional Security (Contd.)

- The prevalence of undernourishment is highest in Africa (as shown in Figure 14.).

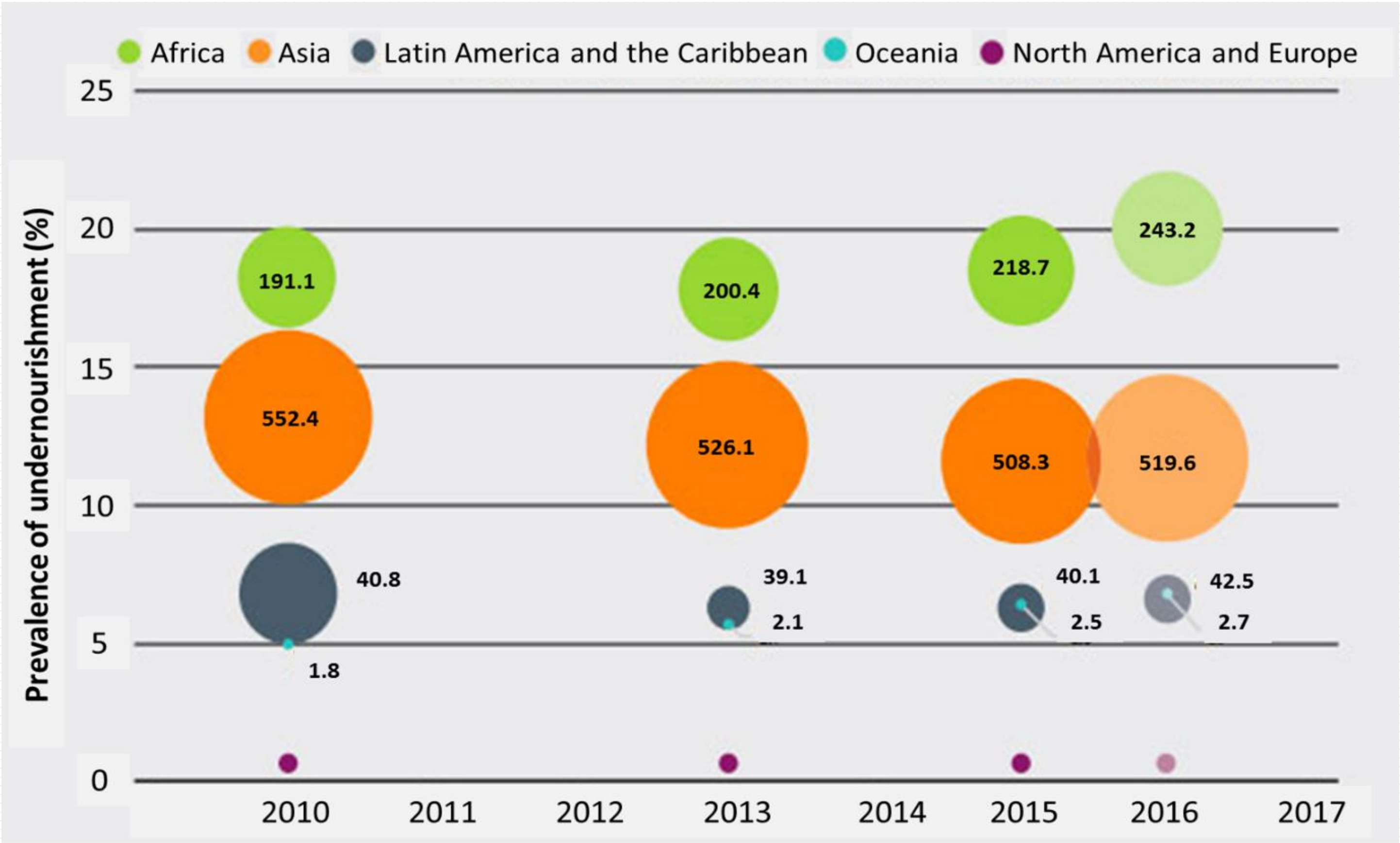

Figure 1.14 The absolute number of undernourished people (Source: FAO, The State of Food Security and Nutrition in the World, 2017 p. 7)

Development of Irrigation Worldwide

- Currently about 20% of the world's total cultivated land is irrigated and this irrigated land produces about 40% of the food and fiber.

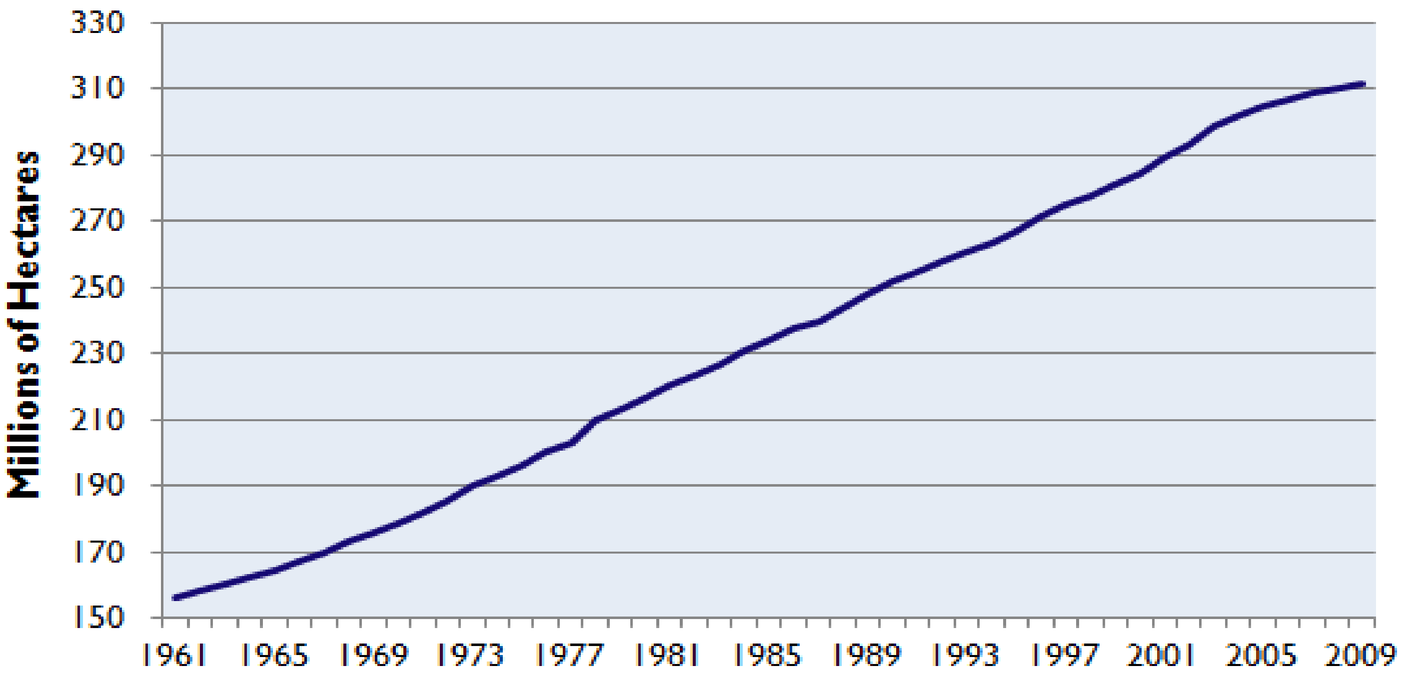

Figure 15. Increase in irrigated land during the 20th century (from FAO, 2009)

Development of Irrigation Worldwide (Contd.)

- Figure 1.16 showcases the top 20 ranked countries in total irrigated land (km^2).

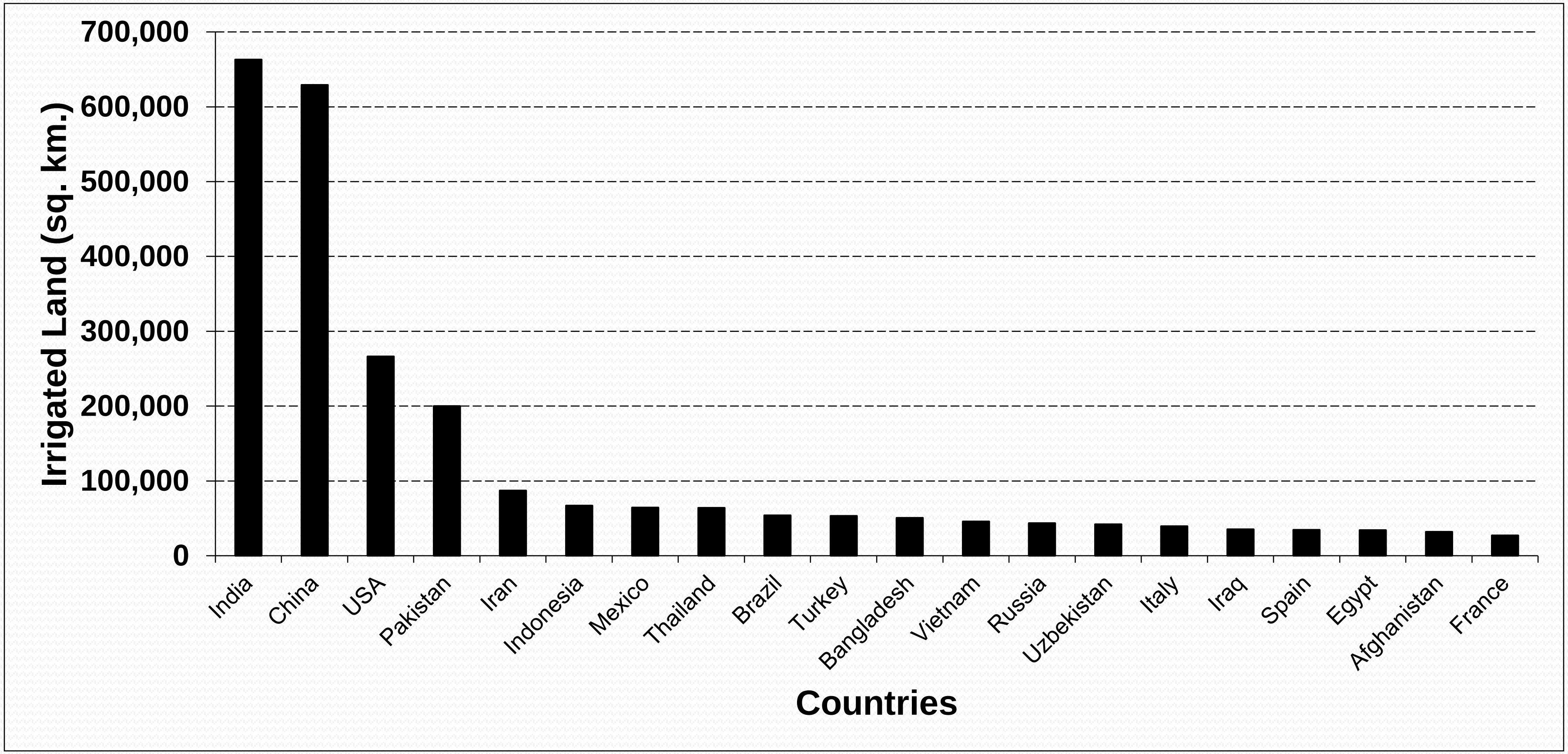

Figure 16. Top 20 nations with maximum irrigated land (km^2) (http://world.bymap.org/IrrigatedLand.html)

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Irrigation in the United States

- Although irrigation in the Southwest existed about 100 B.C., the expansion of irrigation occurred along with the settlement of West but much of the expansion occurred in the 20th century with the support of federal government.

- The irrigated land increased from one million ha in the 1880s to 8 million ha by the middle of the 20th century, primarily in the Southwest, Mountain States, and the Pacific Northwest (U.S. Department of Commerce, 1983).
- In the second half of the 20th century, irrigation expanded to the southern Great Plains, central Great Plains, and southeastern states, largely triggered by the developments in irrigation technologies, such as sprinklers.

Irrigation in the United States (Contd.)

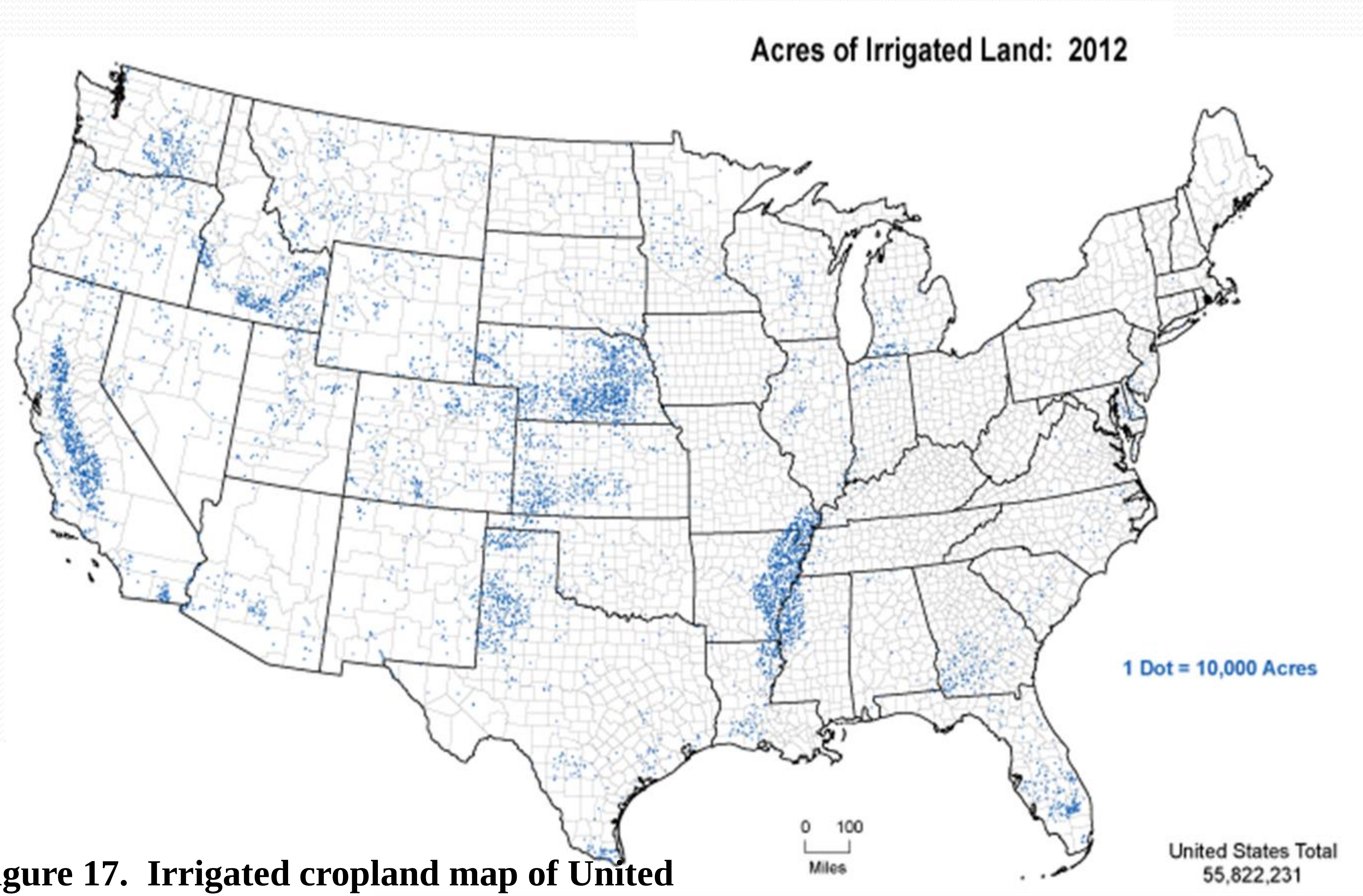

Figure 17. Irrigated cropland map of United States (after USDA, 2013)

Irrigation Practice in the United States

- In the beginning water was diverted from streams by ditches dug by hand. Water was also withdrawn from open dug wells.
- Water storarge reservoirs and canal systems were built.
- Tubewells were developed. Then came sprinklers and microirrigation systems.

- In the latter half of the 20^{th} century, sprinkler technology along with low-cost aluminum and PVC pipe became popular.
- **<u>Now in many areas more cropland is irrigated by sprinklers than by surface irrigation methods.</u>**

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Irrigation Practice in the United States (Contd.)

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Irrigation Practice in the United States (Contd.)

Table 1.7 Cropland irrigated by various methods in the United States: Comparison of irrigation methods in the U.S. in 2013 (adapted from 2012 Census of Agriculture, USDA-NASS, 2014).

Irrigation Method	Irrigated Area (acre)	% of Total
Gravity systems		
Furrow	10,485,453	
Border/basin	8,487,054	
Uncontrolled flooding	1,801,259	
Other	730,918	
U.S. total, gravity systems	21,504,684	35.08
Sprinkler systems		
Center pivot, pressures above 60 psi	1,172,234	
Center pivot, pressures 30 to 59 psi	13,396,454	
Center pivot, pressures below 30psi	12,770,489	
Linear move tower sprinklers (low pressure,<30psi)	257.237	
Linear move tower sprinklers (low pressure,>30psi)	368.329	
Solid set and permanent sprinklers (low pressure,<30psi)	341,288	
Solid set and permanent sprinklers (low pressure,>30psi)	1,145,451	
Side roll, wheel move, or other		
Traveler or big gun	558,308	
Hand move	820,806	
Other sprinkler systems	1,664,496	
U.S. total, sprinkler systems	34,894,109	56.9
Microirrigation systems		
Surface drip	2,583,201	
Subsurface drip	768,901	
Microsprinklers	1,269,483	
Other micro sprinklers	270,327	
U.S. total, microirrigation systems	4,889,912	8.02
Total U.S. irrigation[a]	61,288,705	

[a] The U.S. total irrigated area is larger than the 21.3 million ha quoted previously because more than one irrigation method may be used on some lands.

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An Overview of Irrigation System

- For farming irrigation is almost always required and irrigation systems are therefore planned, designed, built, operated, and managed.

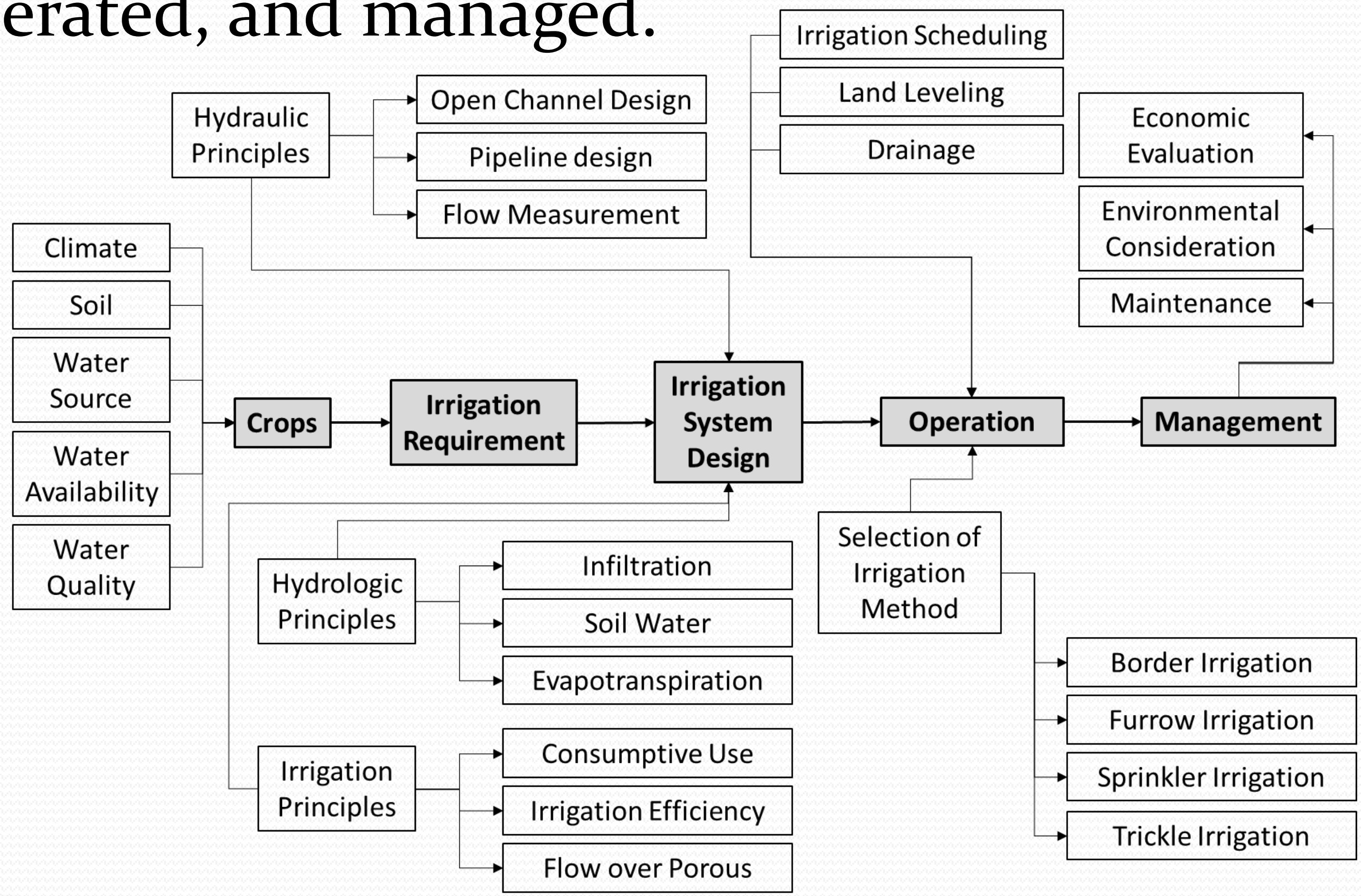

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Figure 1.5 An overview of planning, designing, operating, and maintaining an irrigation system

Considerations for Irrigation Management

- The first consideration is the selection of crops. However, before selecting crops for cultivation on a land, it is important to know five things first, that include climate, soil, source and availability of water and energy, quality of water, and crop types.

- The second consideration includes principles of hydraulics which are needed for bringing water from its source to the field. The water is transported either by open channels or pipelines and often it may need to be lifted using pumps.

Considerations for Irrigation Management (Contd.)

- The third consideration comprises hydrologic principles that are needed for the application of water. Once water is applied to the land, it has four ways to go: vertically downward (infiltration), temporary storage in the pore spaces of soil (soil water), horizontal movement (drainage), and vertically upward (evapotranspiration) combining evaporation and transpiration.
- The fourth consideration is comprised of irrigation principles, that include consumptive use, irrigation efficiency, and equations governing flow over porous beds.

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Consideration for Irrigation Managemnet (Contd.)

- The fifth consideration includes methods of irrigation, including border, furrow, sprinkler, and drip.

- The sixth consideration entails operation and management of irrigation systems including irrigation scheduling, drainage, land leveling, environmental considerations, economic evaluation, and maintenance.

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Impact of Global Warming and Climate Change

- It is now well accepted that the globe is warming and climate is changing and will continue to change in the foreseeable future.
- From an agricultural point of view, the rise in temperature translates into more evaporation and evapotranspiration and changing patterns of precipitation and cropping patterns.
- **Crop growing seasons may also shift.**
- **The hydrologic cycle may be undergoing a change.**
- **Hydrologic extremes, such as droughts and floods, will be occurring more frequently.**
- This will pose a challenge for agriculture, agricultural irrigation, and operation and management of irrigation systems.

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Environmental Concerns

- Irrigated agriculture has both **positive** and **negative** impacts on the environment.
- (+) increase wetlands which serve a variety of useful purposes, such as refuge for migratory and non-migratory birds, wildlife, recreation, reduction in pollution, and groundwater recharge.
- (-) salinization of soil, water logging, declining water table, loss of aquatic and riparian habitats, decline in native species, increase in pollution, decline in fish spawning, etc. may be caused by irrigation.

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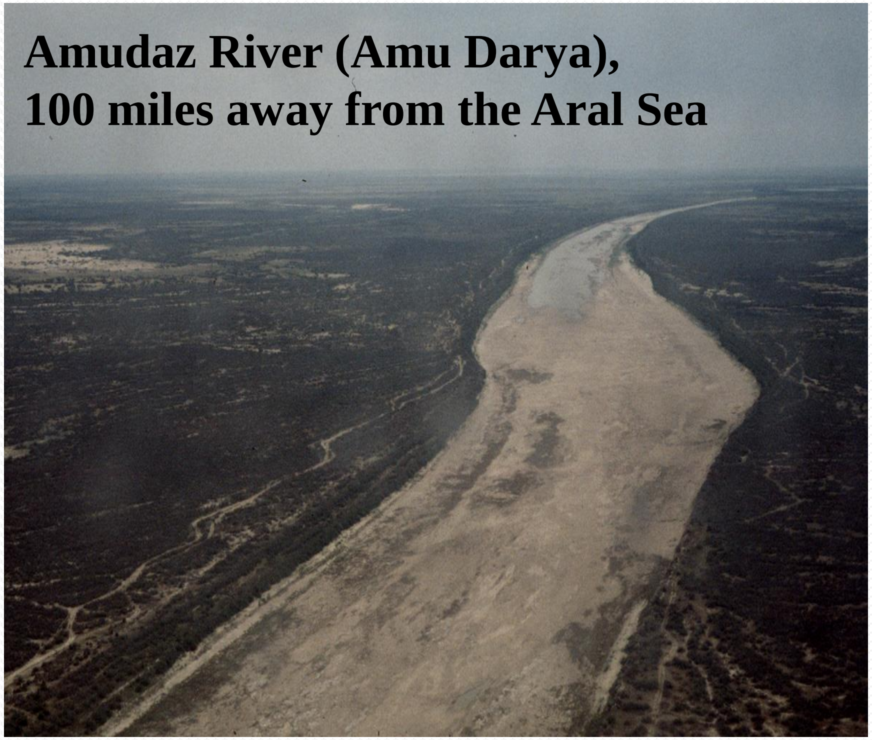
Environmental Concerns (Contd.)

- Aral Sea disaster in Central Asia
- In the 1960s Soviet Union expanded irrigated cotton production that diverted so much water for irrigation that inflows into the Aral Sea virtually ceased which led to the collapse of the sea
- Results in animal and fish extinction



Future of Irrigation

- The **population** will continue to grow **the standard of living** will also be rising → **food demand** will be increasing
- The production can be increased by developing higher yield varieties, increasing irrigated agriculture, and improved irrigation technology.
- In future the pressure on available water resources will increase.

→ a decline in the amount of water available now for agriculture.

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Future of Irrigation (Contd.)

- For sustained agricultural productivity, irrigation technology will have to be more efficient and better managed and will have to compete with these other sectors.
- Water allocated for irrigation will have to be justified and it might involve water pricing.

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THANK YOU

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