TODAY'S GOALS

- Drinking water and wastewater treatment
  - Early drinking water treatment
  - Epidemics and the microscope
  - Federal protection of drinking water
  - Drinking water issues: past and present
  - Wastewater treatment: past and present
- At the end of the lecture, we should be able to identify potential issues with drinking water and wastewater, as well as how to minimize or eliminate those issues.

- Mercury contamination
  - Why do we care about mercury contamination?
  - How are mercury compounds classified?
  - Mercury cycle
- At the end of the lecture, we should be able to understand how mercury affects organisms, ecosystems, and the water cycle.

INTRODUCTION TO WATER TREATMENT

"Water is fundamental for a life of human dignity. It is a prerequisite to the realization of all other human rights."

- World Health Organization

EARLY DRINKING WATER TREATMENT

- Methods:
  - Filtering through charcoal, sand, and gravel
  - Water placed in sunlight, boiled, inserted hot instruments into the water, and strained
- Reasons:
  - Not to disinfect (had no knowledge of microbial life and pathogens)
  - To improve its taste
- Examples:
  - Ancient Egyptians used alum as a flocculant (forces particulate matter to clump together and sink to the bottom)
  - Ancient Greeks lined their water transportation tunnels with ceramic tiles and posted guards at every fountain to ensure no one polluted the water

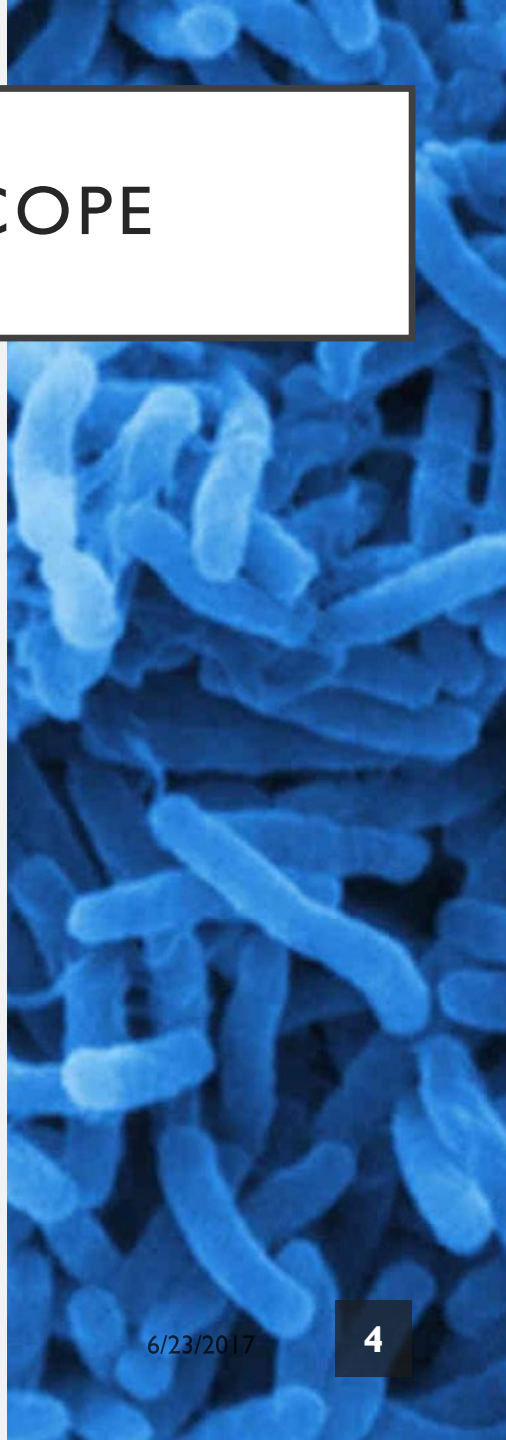
EPIDEMICS AND THE MICROSCOPE

Microscope timeline

- 1595 – First tube with lenses built (3-9x)
- 1665 – Improved and drawings of microbes were published (30x)
- ~1700 – Adjustable optics and careful lens polishing (200x)

Epidemics

- Prior to the 1800s, diseases were believed to have come from evil spirits or bad air
- Cholera outbreak of 1854, Dr. John Snow was suspicious about the origins.
  - He conducted interviews and marked the outbreak sites on a map, which created a pattern, later identified as a particular fountain pump
  - Taking a sample of the water, he then observed the bacteria under a microscope
  - He also found the source of the contamination as a leaky cesspool near the pump site



FEDERAL PROTECTION OF DRINKING WATER

- 1914 – First restrictions regarding bacteria
- 1920s – Filtration and chlorination was common
- 1942 – The first official drinking water standards were enacted
- 1974, 1986, 1996 – More strict regulations including, not only drinking water treatment guidelines, but also protections for the source water

- Now, states can set their own guidelines (with Federal minimums in place) but the EPA can reject them if they are insufficient
- The EPA also sets the maximum contaminant levels (MCLs)

DRINKING WATER ISSUES

THEN

- Biological (parasites, bacteria, viruses…)
- Inorganic chemicals (cyanide, fluoride, heavy metals, also lead pipes)
- Fertilizers (Phosphates, nitrates!!)
- Organic chemicals (DDT, PCB, typically carcinogenic agents)
- Radioactive elements (radium, uranium, nuclear waste sites, nuclear testing)

NOW

- MTBE (methyl tertiary butyl ether) – carcinogen
- Perchlorates (in missiles, fireworks and a few fertilizers) – carcinogen
- Arsenic (pesticides, semiconductors, alloys, batteries, LEDs) – toxic
- One billion people still do not have safe drinking water!!!
- Waterborne illnesses account for the deaths of 2 million babies every year!!!

WASTEWATER TREATMENT

THEN

- NONE!
- Chamber pots emptied them into the street from 5-6 stories up!
- Later, canals and rudimentary sewers transported the waste and dumped it in a nearby river (hopefully downstream from the drinking water source)
- The Black Death or Bubonic Plague (1347-1350)
  - Killed 40% of people in Europe
  - 75 million people worldwide

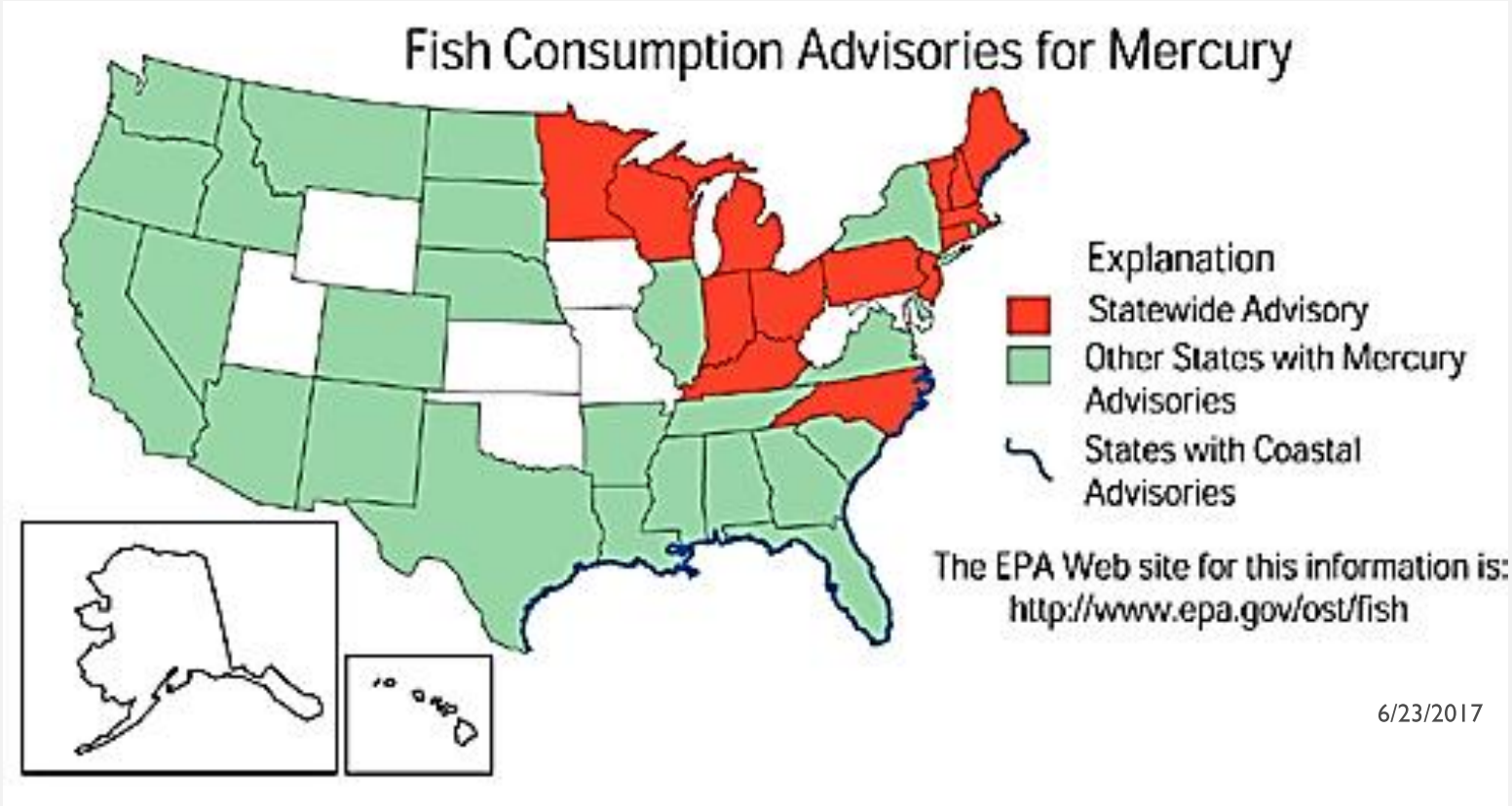
NOW

- Prior to 1972, debris, oil, sludge, industrial wastes, and sewage were dumped into rivers unregulated
  - Consider industrial waste – unexpected example in Omaha – cattle and hog packing plants would dump blood and offal into the Missouri River
- The Clean Water Act of 1972 required every city with >100,000 people to install wastewater treatment plans/facilities
- Today, >70% of rural households in Vietnam have NO bathroom facilities

MERCURY CONTAMINATION

WHY DO WE CARE ABOUT MERCURY CONTAMINATION?

- Health effects
  - Nervous system
  - Kidneys
- Environmental effects
  - Plants and Bacteria
  - Food chain



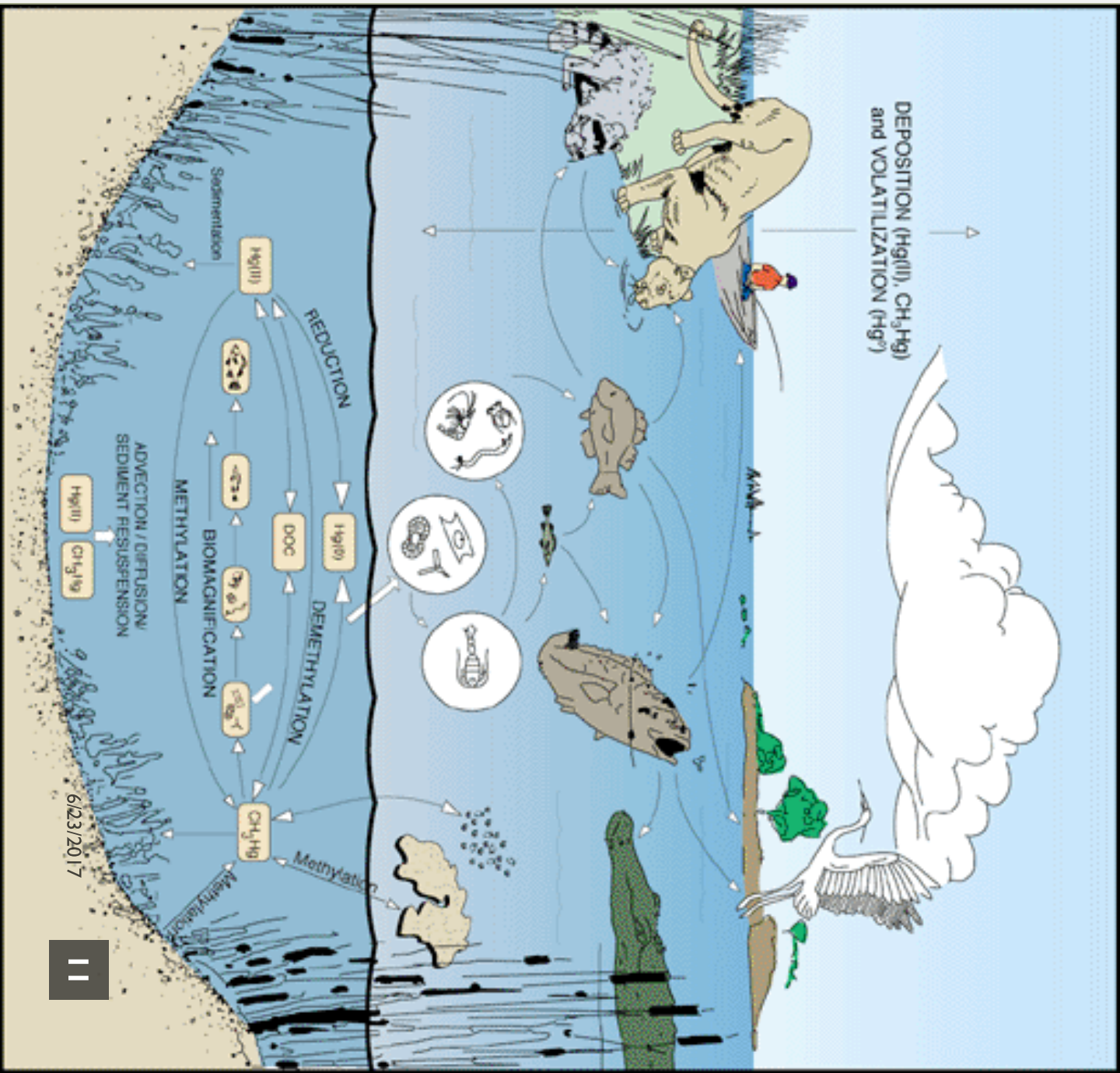
CLASSIFICATION OF MERCURY COMPOUNDS

- Elemental Mercury
  - Hg^0
  - Hg_2^{2+}
  - Hg^{2+}
- Inorganic mercury
  - $HgCl_2$, Hg_2Cl_2, HgS, $HgC_4H_6O_4$
- Methylmercury
  - CH_3Hg^+
  - Easily forms complexes with anions, such as Cl^-, OH^-, NO_3^-
  - Thiols

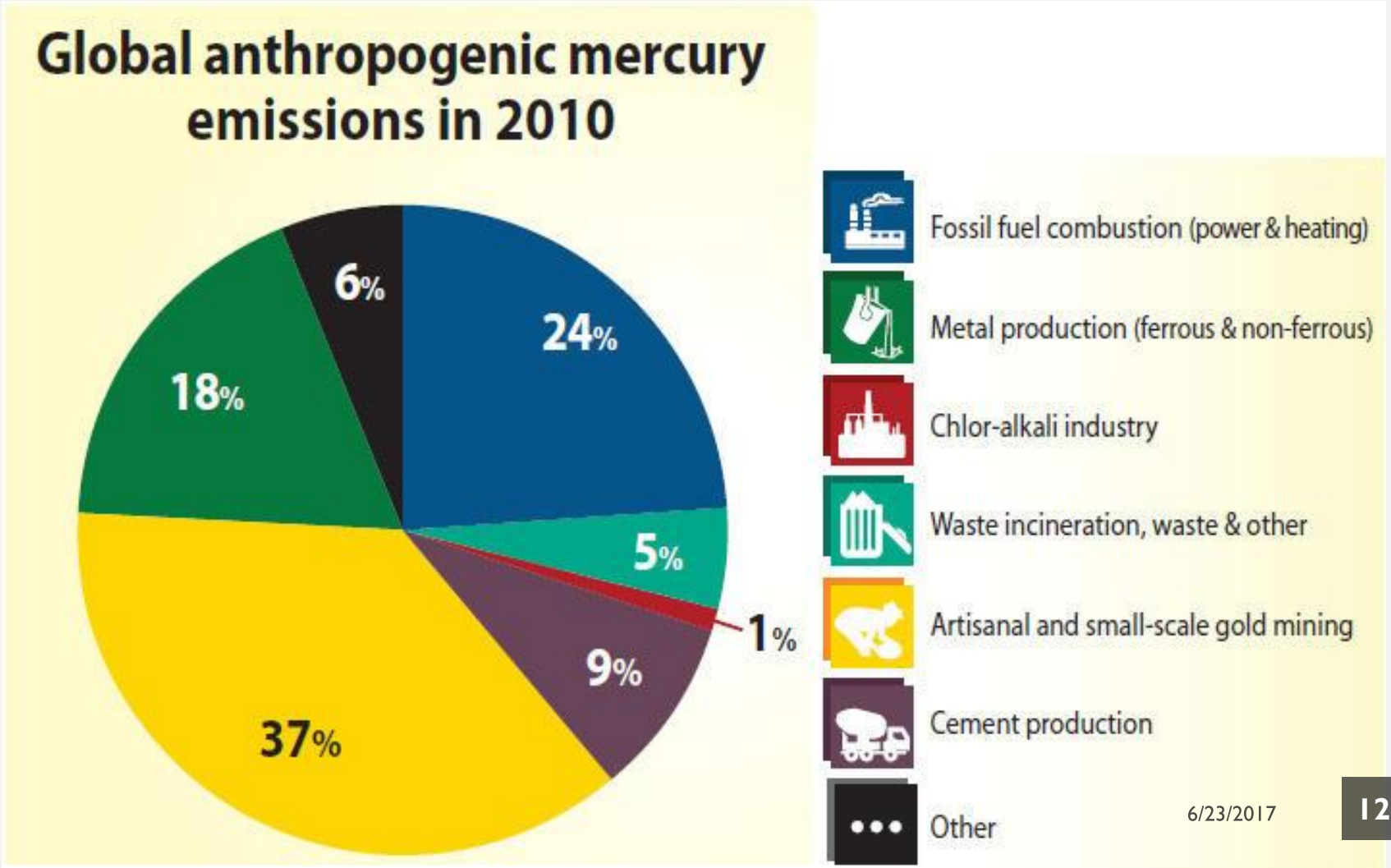
Yin, R., et al. (2010). Applied Geochemistry **25**(10): 1467-1477.

THE MERCURY CYCLE

www.usgs.gov. Accessed Sept 2014.

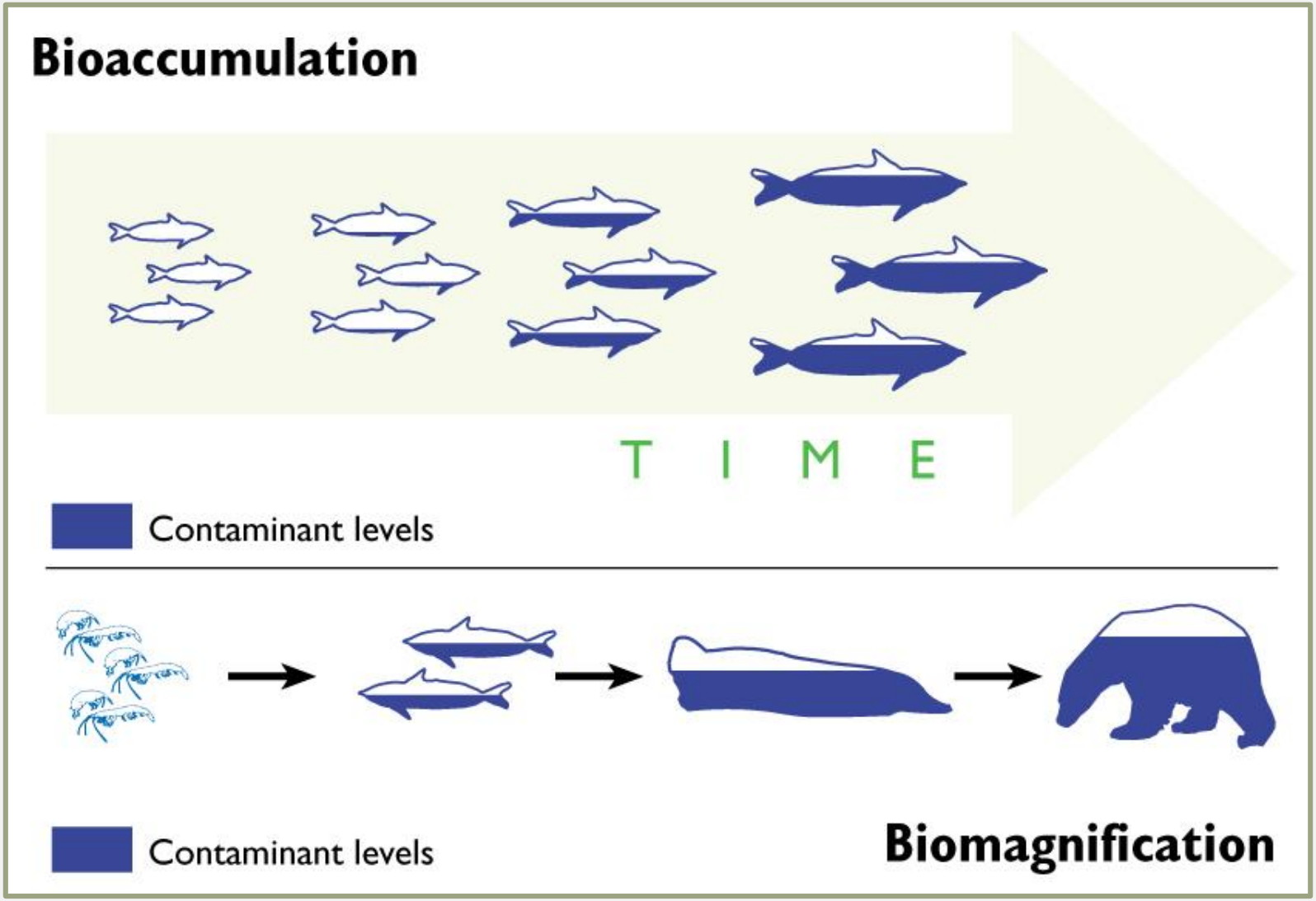


HOW DOES MERCURY ENTER OUR WATER SUPPLY?



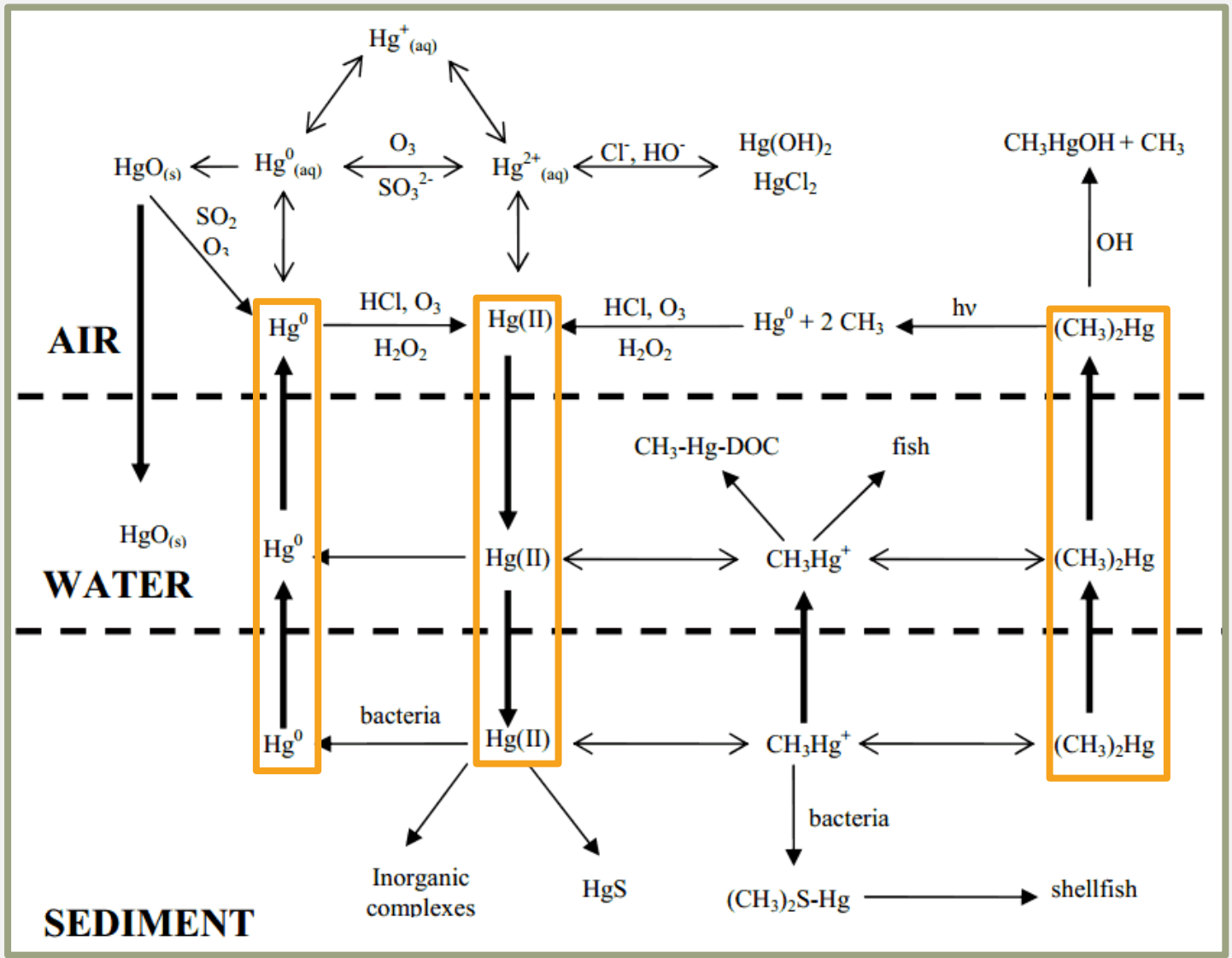
www.epa.gov/mercury.Accessed Sept 2014.

WHAT HAPPENS ONCE THE MERCURY HAS ENTERED THE WATER SUPPLY?



Julie van der Hoop, MIT, 2013

CHEMICAL REACTIONS - PHASES



Farina, M., et al. (2011). *Life Sciences* **89**(15-16): 555-563.

$Hg^{2+} + OH^- \leftrightarrow Hg(OH)^+$

$Hg^{2+} + Cl^- \leftrightarrow HgCl^+$

$CH_3HgCl(g) \leftrightarrow CH_3HgCl(aq)$

$(CH_3Hg)_2S \rightarrow (CH_3)_2Hg + HgS$

$(CH_3)_2Hg + H^+ \rightarrow CH_4 + CH_3Hg^+$

$Hg(OH)_2(g) \leftrightarrow Hg(OH)_2(aq)$

$Hg(CH_3)_2(g) \leftrightarrow Hg(CH_3)_2(aq)$

$Hg^0(g) \leftrightarrow Hg^0(aq)$

$(CH_3)_2Hg \rightarrow CH_3Hg + CH_3$

$Hg^{2+} + 4\ Cl^- \leftrightarrow HgCl_4^{2-}$

$Hg^{2+} + 3\ Cl^- \leftrightarrow HgCl_3^-$

$Hg^{2+} + C_2O_4^{2-} \leftrightarrow HgC_2O_4$

$Hg^{2+} + 2\ Cl^- \leftrightarrow HgCl_2$

$2CH_3Hg^+ + HS^- \rightarrow (CH_3Hg)2S + H^+$

$Hg^{2+} + 2\ OH^- \leftrightarrow Hg(OH)_2$

$Hg^{2+} + 2\ SO_3^{2-} \leftrightarrow Hg(SO_3)_2^{2-}$

$4CH_3Hg^+ + 2H_2O + 4H^+ \rightarrow 3CH_4 + CO_2 + 4Hg^{2+} + 4H_2$

$CH_3Hg \rightarrow Hg + CH_3$

$HgCl_2(g) \leftrightarrow HgCl_2(aq)$

$Hg^{2+} + SO_3^{2-} \leftrightarrow HgSO_3$

CHEMICAL REACTIONS

Environment

$$Hg^0 + CH_4 \leftrightarrow HgCH_3^- + H^+$$

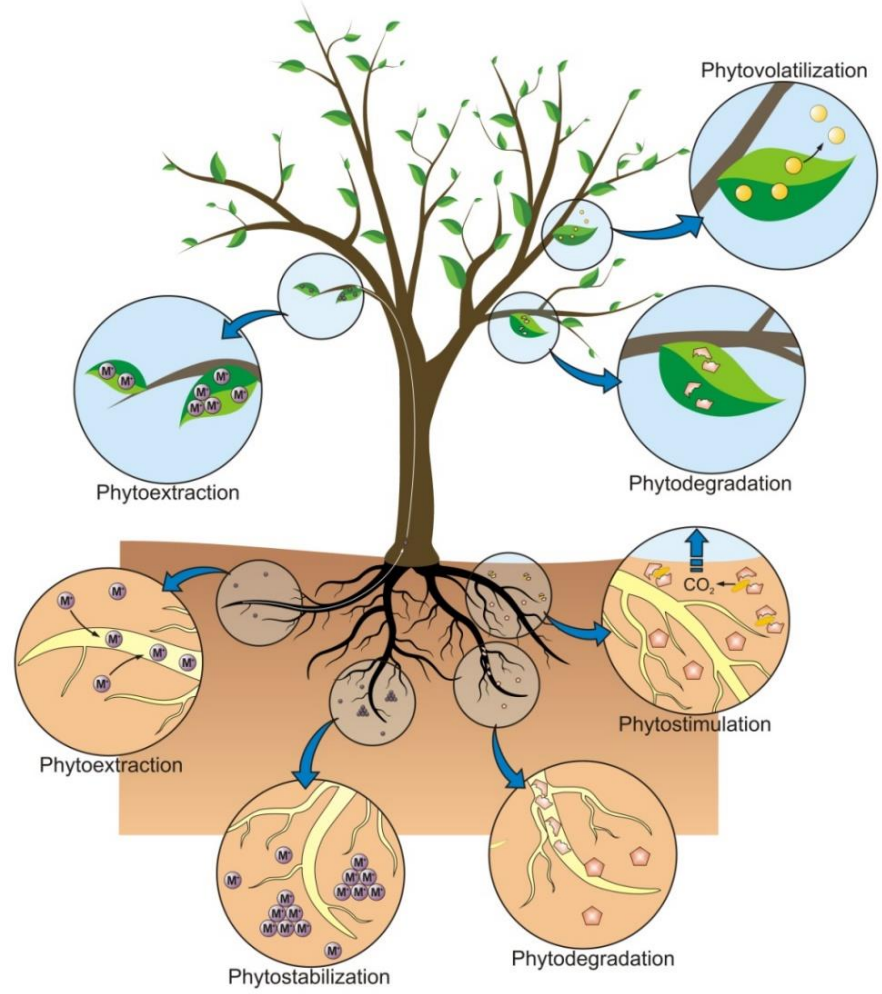
$$HgCH_3^+ + CH_4 \leftrightarrow Hg(CH_3)_2 + H^+$$

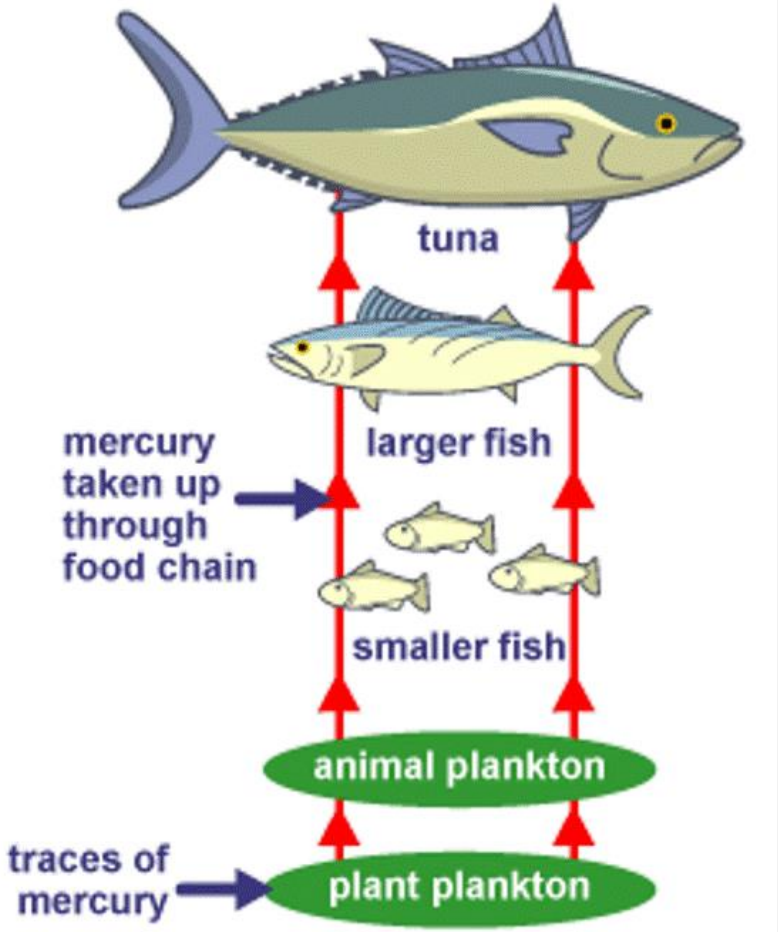
Body

$$Hg(CH_3)_2 \xrightarrow{h\nu} Hg^0 + 2CH_4$$

$$2CH_3Hg^+ + HS^- \rightarrow (CH_3Hg)_2S + H^+$$

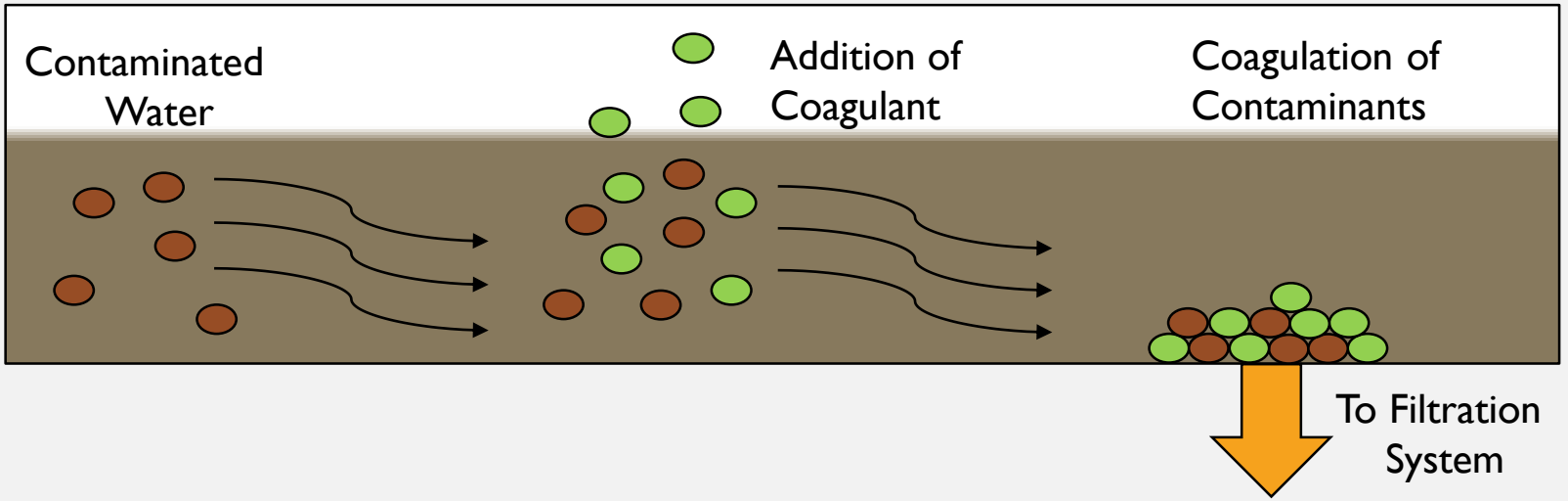
HOW DOES MERCURY EXIT THE WATER SUPPLY? ABSORPTION BY PLANTS/ANIMALS





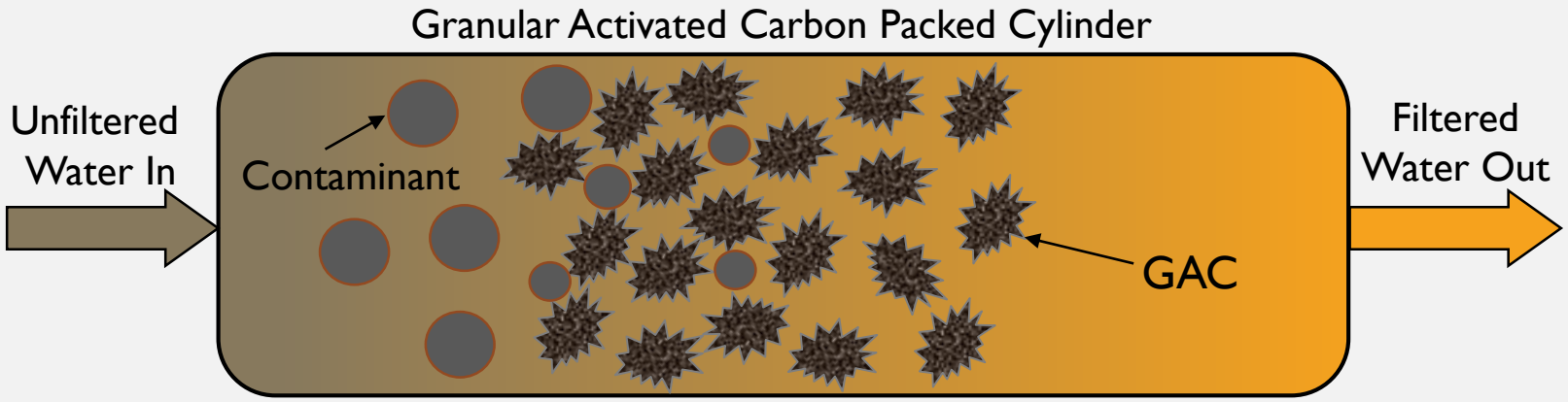
HOW DOES MERCURY EXIT THE WATER SUPPLY? REMOVAL FROM DRINKING WATER

- Coagulation/Filtration methods use metal salts that bind to metals, including mercury, allowing for it to be filtered out of the water.
- Coagulant Formulas: $FeCl_3$, $Fe_2(SO_4)_3$, $Al_nCl_{(3n-m)}(OH)_m$



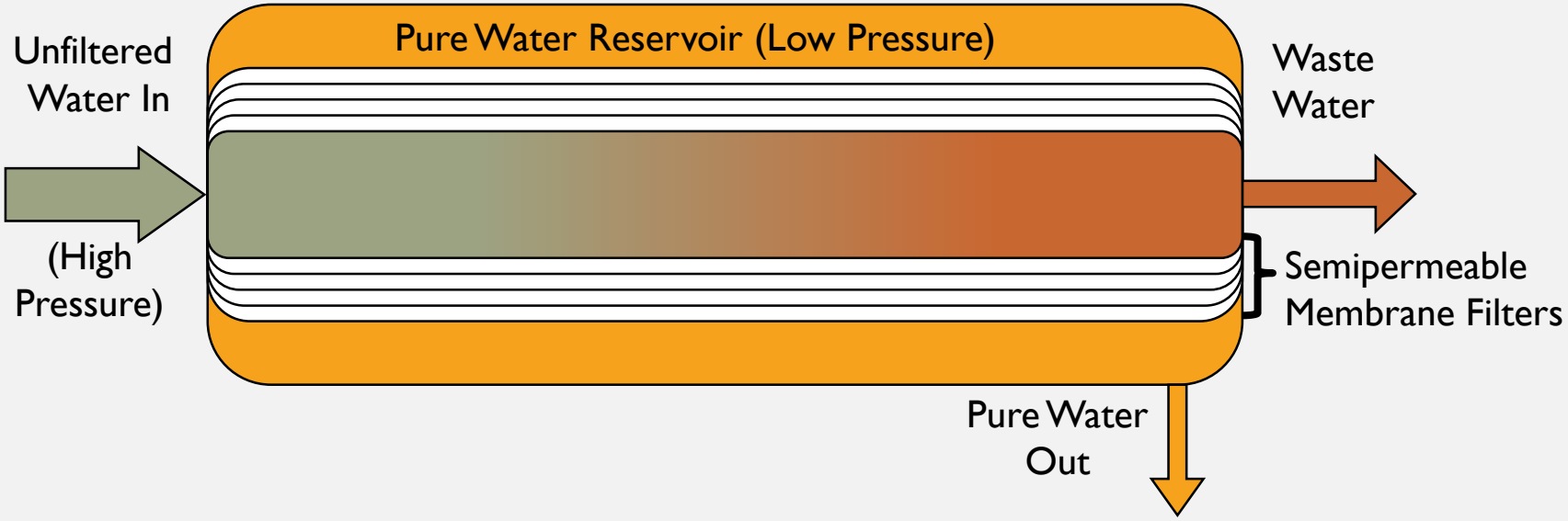
HOW DOES MERCURY EXIT THE WATER SUPPLY? REMOVAL FROM DRINKING WATER

- Granular Activated Carbon is a highly porous carbon structure usually derived from plant material.

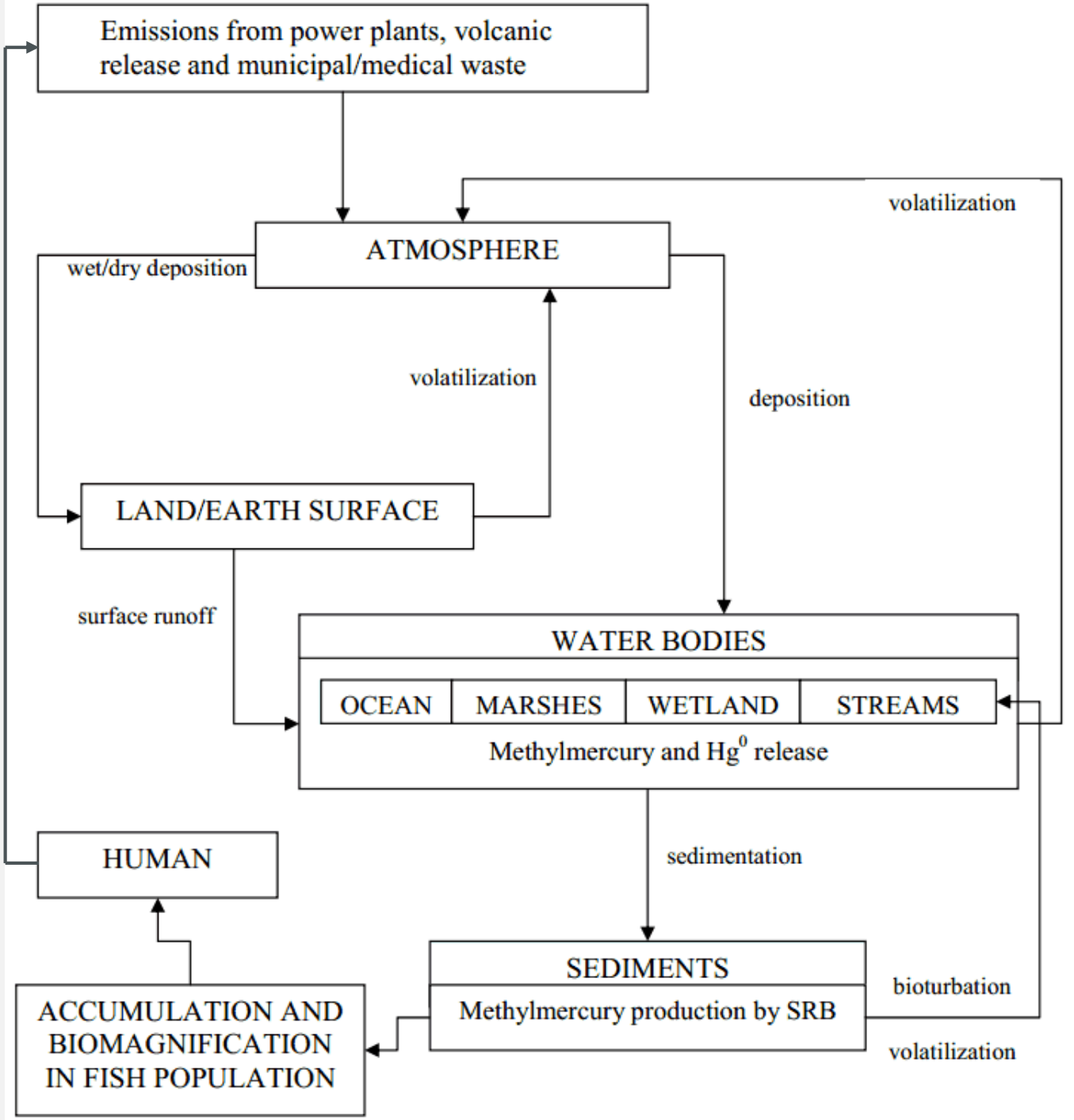


HOW DOES MERCURY EXIT THE WATER SUPPLY? REMOVAL FROM DRINKING WATER

- Osmosis is the spontaneous net movement of solvent molecules through semipermeable membrane into a region of higher solute concentration



CONCLUSION


Emissions from power plants, volcanic release and municipal/medical waste
volatilization
ATMOSPHERE
wet/dry deposition
volatilization
deposition
LAND/EARTH SURFACE
surface runoff
WATER BODIES
OCEAN
MARSHES
WETLAND
STREAMS
Methylmercury and Hg^0 release
HUMAN
sedimentation
SEDIMENTS
Methylmercury production by SRB
bioturbation
volatilization
ACCUMULATION AND BIOMAGNIFICATION IN FISH POPULATION