Project Update:

Domestic Wastewater Cooling Technology Alternatives Feasibility Analysis

PRESENTED TO THE COLORADO WATER QUALITY FORUM

MARCH 5, 2018

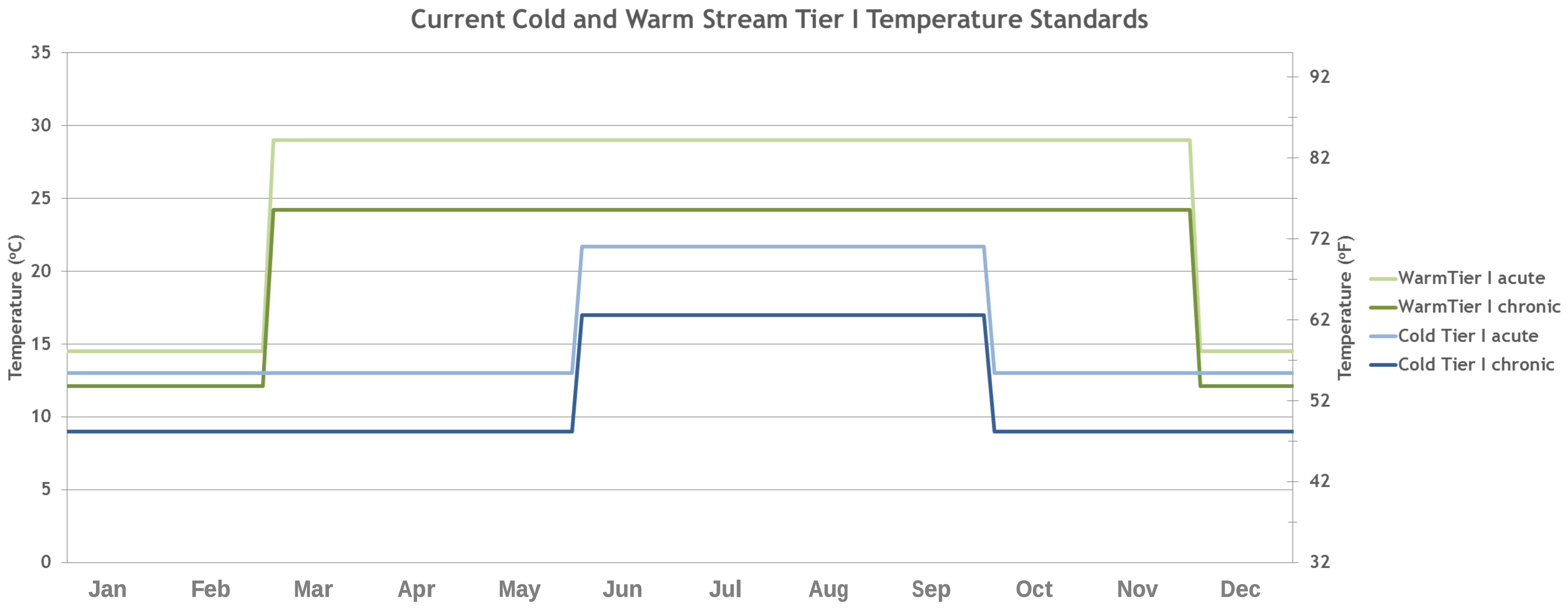
Presentation Overview

Background
- Temperature standards
- Facility data
- Discharger specific variances

Feasibility Study
- Scope
- Report Structure
- Technology Categorization and Examples
- General Results
- Innovative, Hybrid, and Combination Approaches

Next Steps

Temperature Standards



Temperature Standards

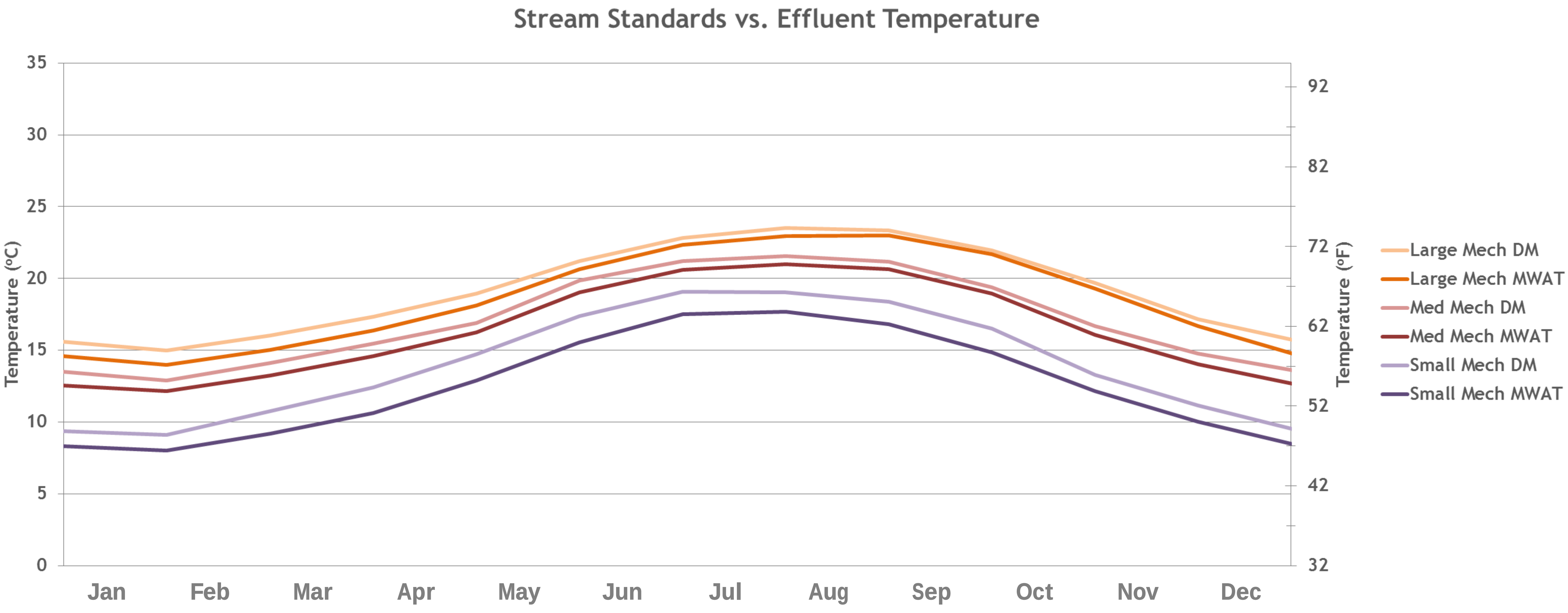
Acute limits are implemented as Daily Maximum (DM) Permit Limits at Domestic WWTFs

DM = highest 2-hour rolling average temperature in a monthly period

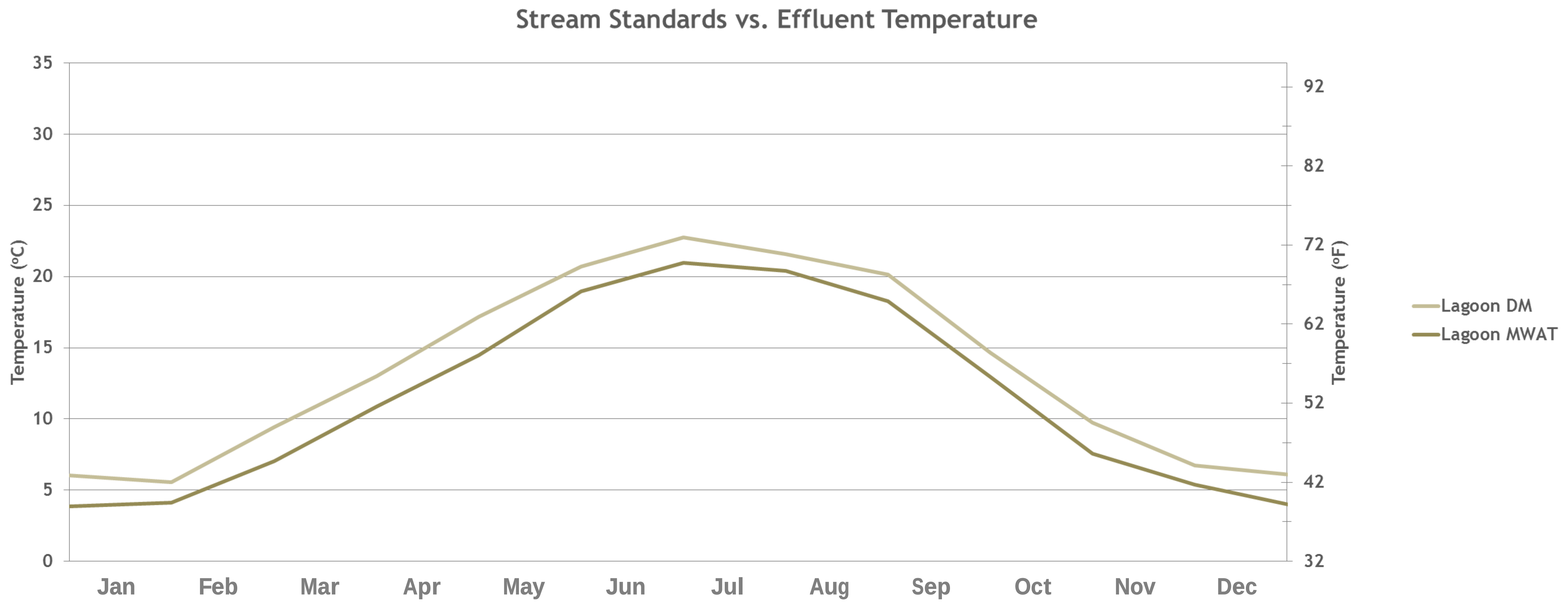
Chronic limits are implemented as Maximum Weekly Average Temperature (MWAT) Permit Limits

MWAT = highest 7-day rolling average temperature in a monthly period

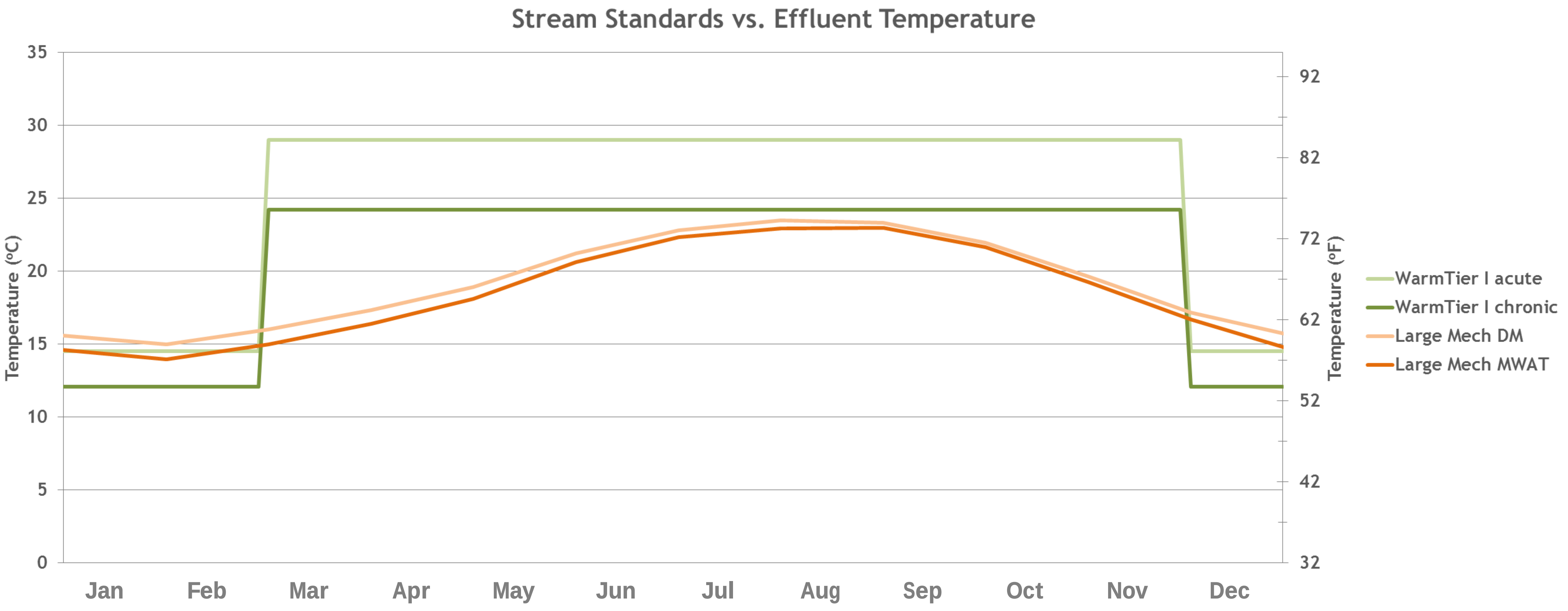
Effluent Temperature Mechanical Facilities



Effluent Temperature Lagoon Facilities



Potential Compliance Problem



Discharger Specific Variances (DSVs)

- DSVs are temporary, facility-specific water quality standards
- Colorado adopted current provisions in 2010, became effective in 2013
- EPA adopted framework in 2015, generally consistent
- WQCC Regulation 31, Section 31.7 (4):

  Variances to numeric standards are authorized only where a comprehensive alternatives analysis demonstrates that there are **no feasible alternatives** that would allow for the regulated activity to proceed without a discharge that exceeds water quality-based effluent limits.

DSV – Feasibility Tests

Limits of Technology: Demonstration that attaining the water quality standard is not feasible because, as applied to the point source discharge, pollutant removal techniques are not available or it is **technologically infeasible** to meet the standard;

Economics: Demonstration that attaining the water quality standard is not feasible because meeting the standard, as applied to the point source discharge, will cause **substantial and widespread adverse social and economic impacts** in the area where the discharge is located. Considerations include such factors as the cost and affordability of pollutant removal techniques; or

Other Consequences: Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would **cause more environmental damage to correct** than to leave in place.

Feasibility Study Impetus

- Multiple dischargers with various pollutants have pursued a DSV
- Challenges regarding scope/level of detail in DSV alternatives analysis
- Funds through CWRPDA earmarked for temperature reduction study
- WQCD is working to develop comprehensive technical guidance with multiple pollutant-specific fact sheets, including T, NH_3, TIN, Se, etc.

Scope of Feasibility Study

- Identify temperature reduction alternatives
- Categorize and select representative technologies for analysis
- Develop and apply sizing/costing methodology
- Administer questionnaire to other states
- Prepare guidance document, including:
    - Applicability and limitations of each technology
    - Planning level cost estimates
    - Generalized environmental impacts
    - Considerations for temperature related DSV applications

Beyond Scope of Project

The following items are not included or intended for the project:

- Develop novel or innovative treatment approaches
- Provide detailed design procedures
- Create categorically eligible facilities
- Decide if environmental impacts are worse than leaving in place
- Establish methodology to determine Alternate Effluent Limits

Status of Feasibility Studies

- Final phase of drafting and internal review
- Guidance should be published this spring

Technology Categorization

Categories based on underlying heat transfer mechanisms allows simplification by identifying a spectrum of representative technologies for:

- Source Control, Site Considerations, and Other Mitigation Options
- Natural Heat Flow
- Evaporative Cooling
- Mechanical Cooling

Source Control/Other Mitigation Options

A lot of heat in domestic wastewater comes from residential water use. How much comes from industrial, commercial, or retail sources?

Encouraging residents to minimize hot water use alone may not achieve compliance, but it can be easily incorporated into any DSV proposal

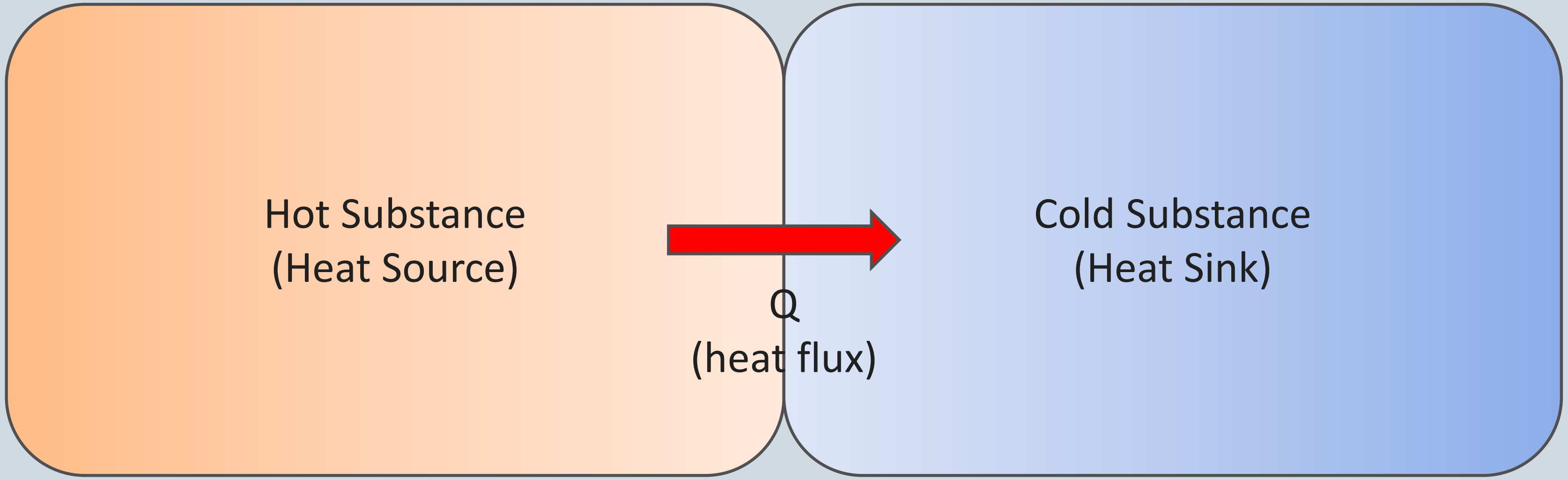
Potential Source Control Options:

- Outreach and education to residential users
- Evaluate heat loads from industrial, commercial, and retail sources
- Consider implementing voluntary or mandatory controls for select users
- Options at WWTF are limited (more on this in solar shade section)

Other non-technologic options (alternate discharge locations, consolidation, etc.) are highly site-specific and beyond scope of feasibility study.

Natural Heat Flow

Heat energy transfers from areas of high temperature to areas of low temperature

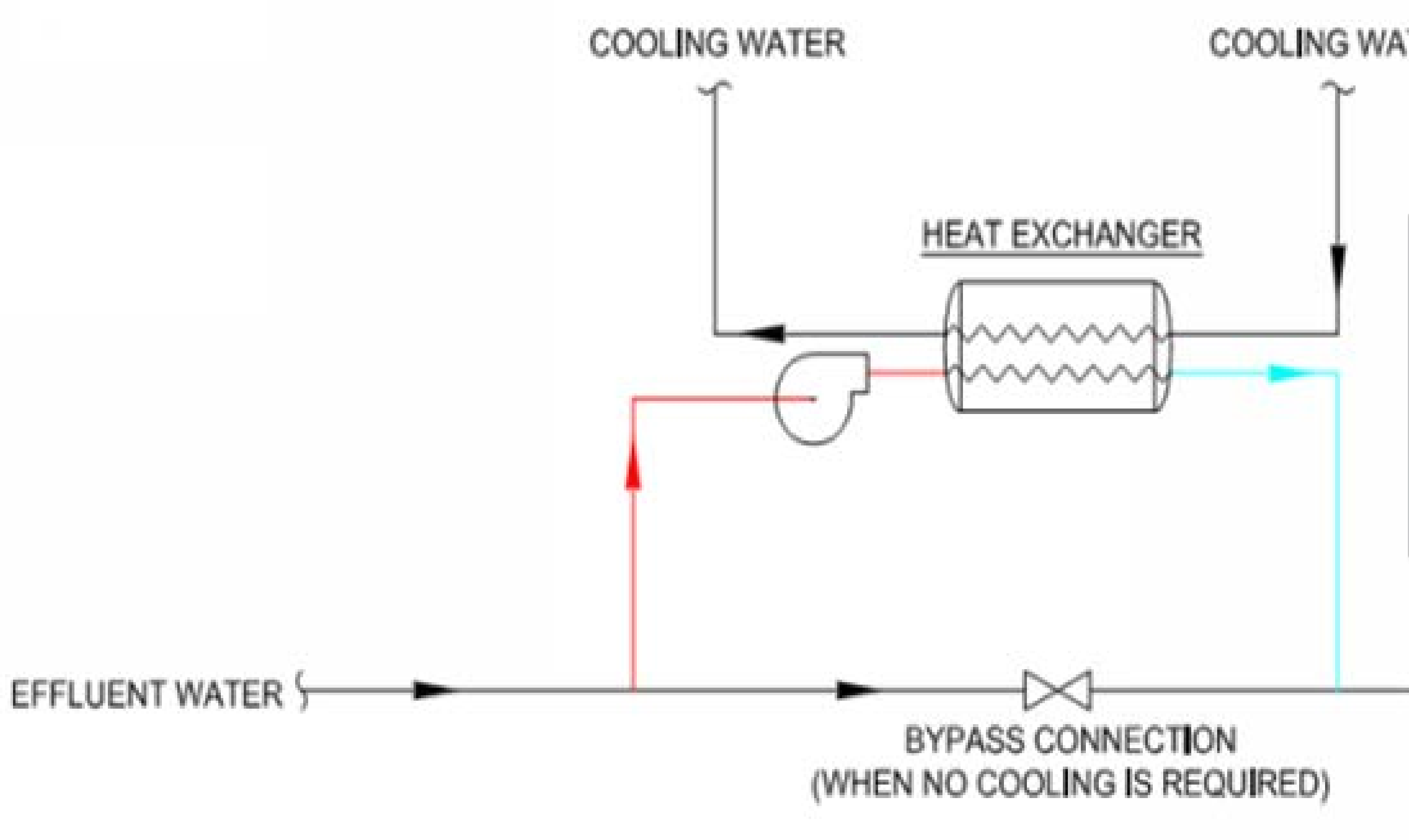


$$Q = U_{overall} * Area * (T_{source} - T_{sink})$$

$U_{overall}$ = overall heat transfer coefficient, varies based on substance properties

Natural Heat Flow

Example: Heat Exchanger – allows natural heat flow but keeps fluids separate



The outlet wastewater temperature can never get below the inlet cooling water temperature

Natural Heat Flow

Limit of Technology:

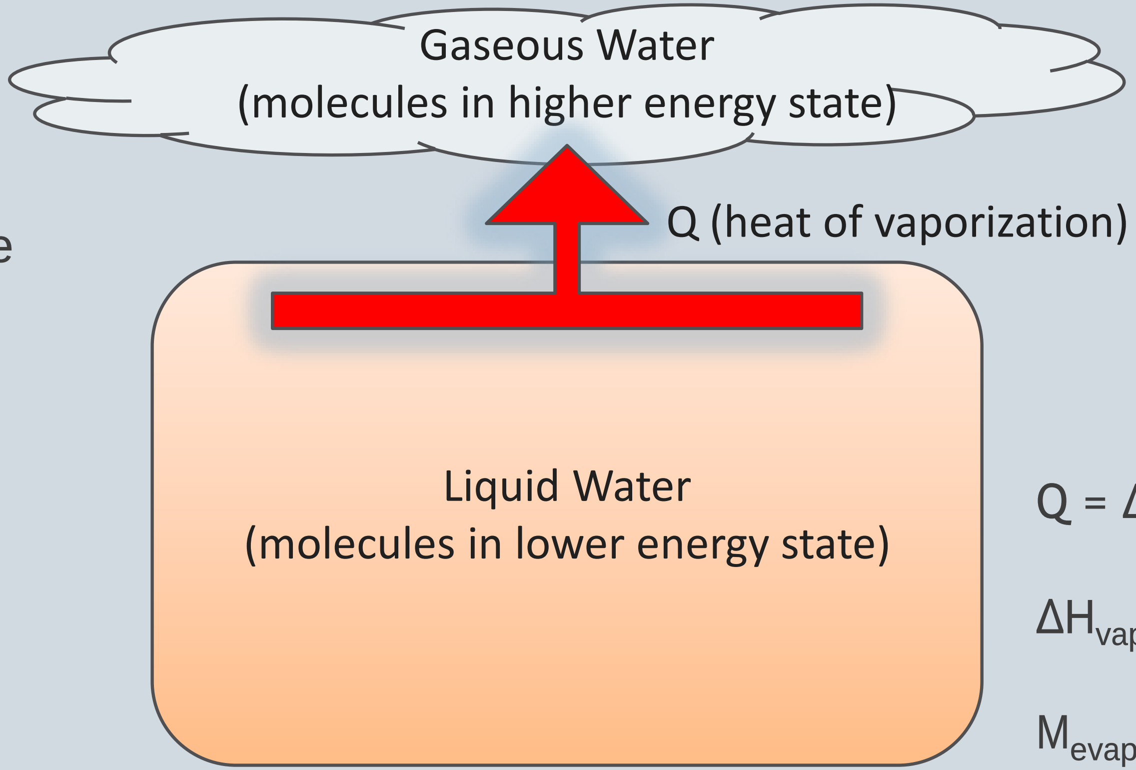
Natural heat flow cannot cool wastewater below the temperature of the heat receiving sink (e.g. soil, groundwater, surface water, other cooling fluid, ambient air)

$$T_{effluent} > T_{sink}$$

Evaporative Cooling

Energy is taken up and stored in gaseous water molecules

In order to change phase (i.e. evaporate), water molecules will "steal" energy from nearby molecules to get to the higher energy state



$Q = \Delta H_{vap} * M_{evap}$

ΔH_{vap} = heat of vaporization (latent heat)

M_{evap} = Mass of water evaporated

Evaporative Cooling

What is the wet bulb (WB) temperature?

The lowest temperature that can be reached by evaporating water into the air.

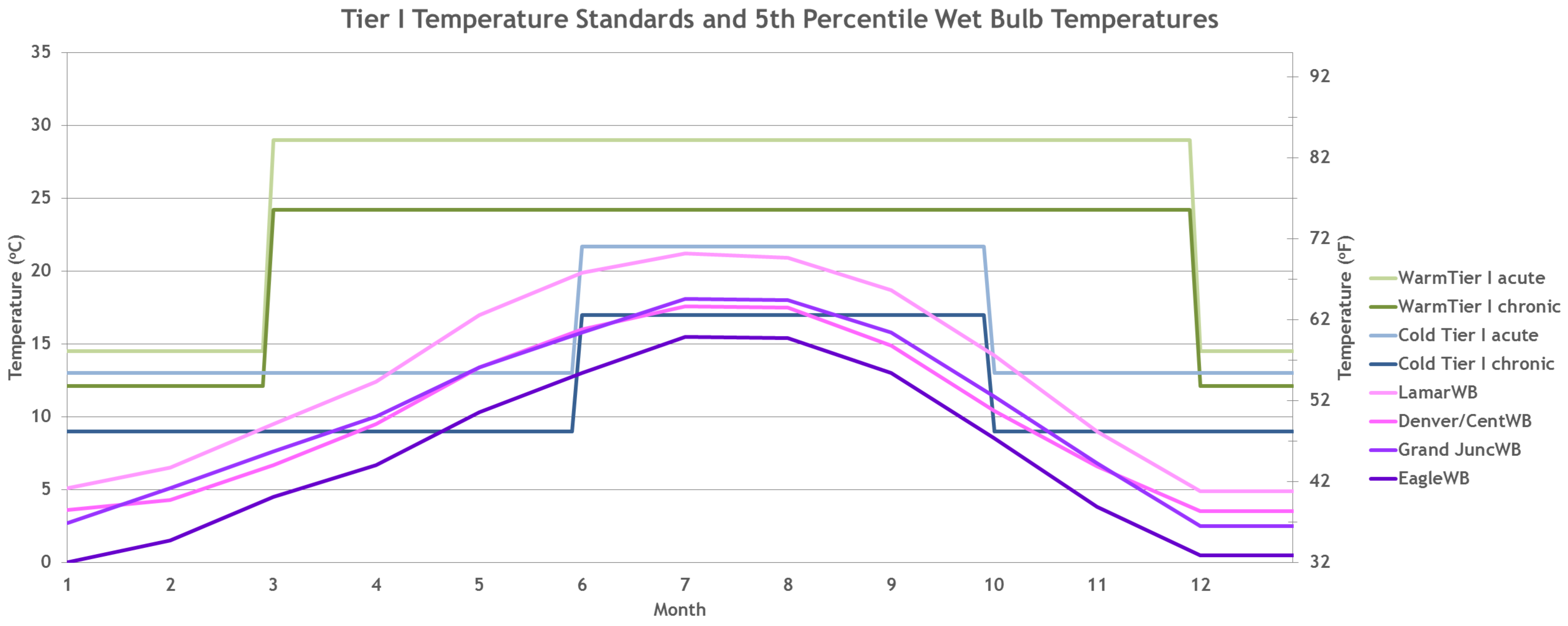
- Measured by placing a wetted muslin sock on a thermometer with air blowing over it.

- Combines the ambient air temperature (aka dry bulb (DB) temperature) and the relative humidity into one factor that shows the limit to which evaporation can be used for cooling.

Note:

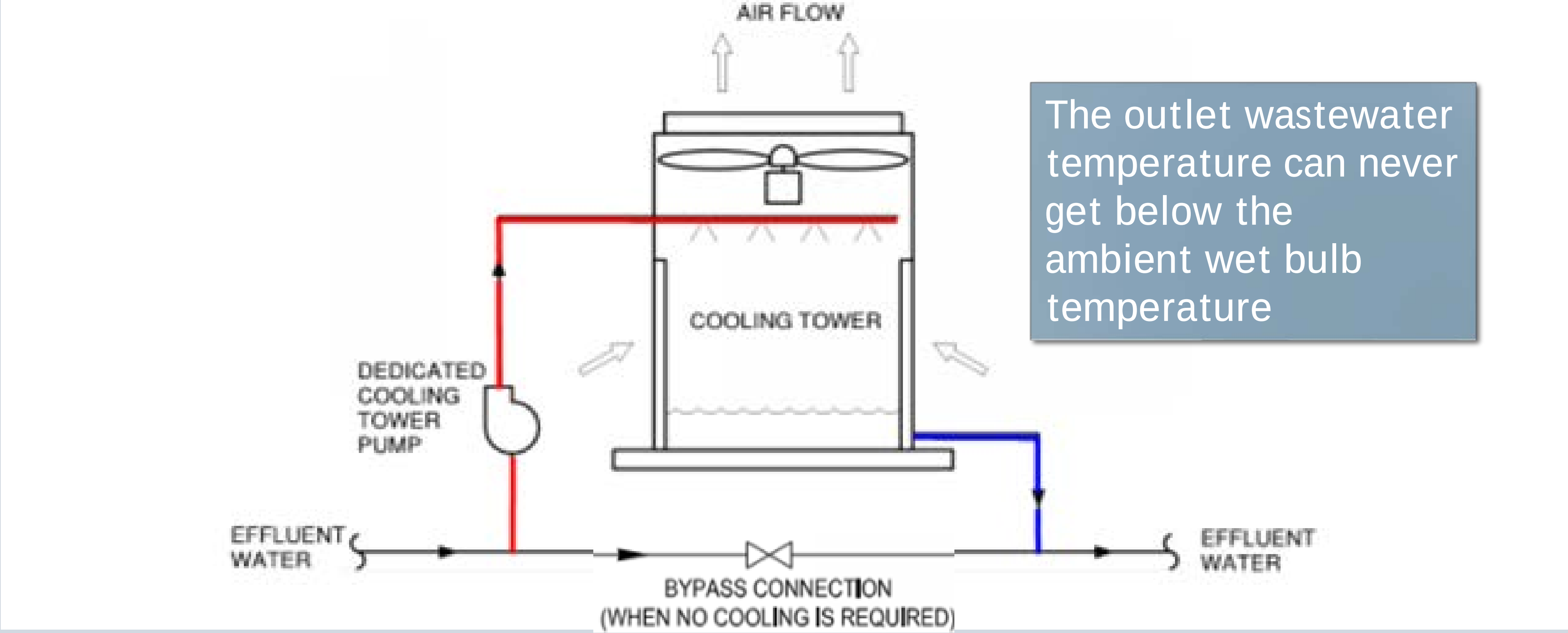
- When relative humidity = 100%, wet bulb = dry bulb
- When relative humidity < 100%, wet bulb < dry bulb
- Therefore: wet bulb ≤ dry bulb

Evaporative Cooling



Evaporative Cooling

Example: Once-through Cooling Tower – optimization of air to water contact



The outlet wastewater temperature can never get below the ambient wet bulb temperature

Evaporative Cooling

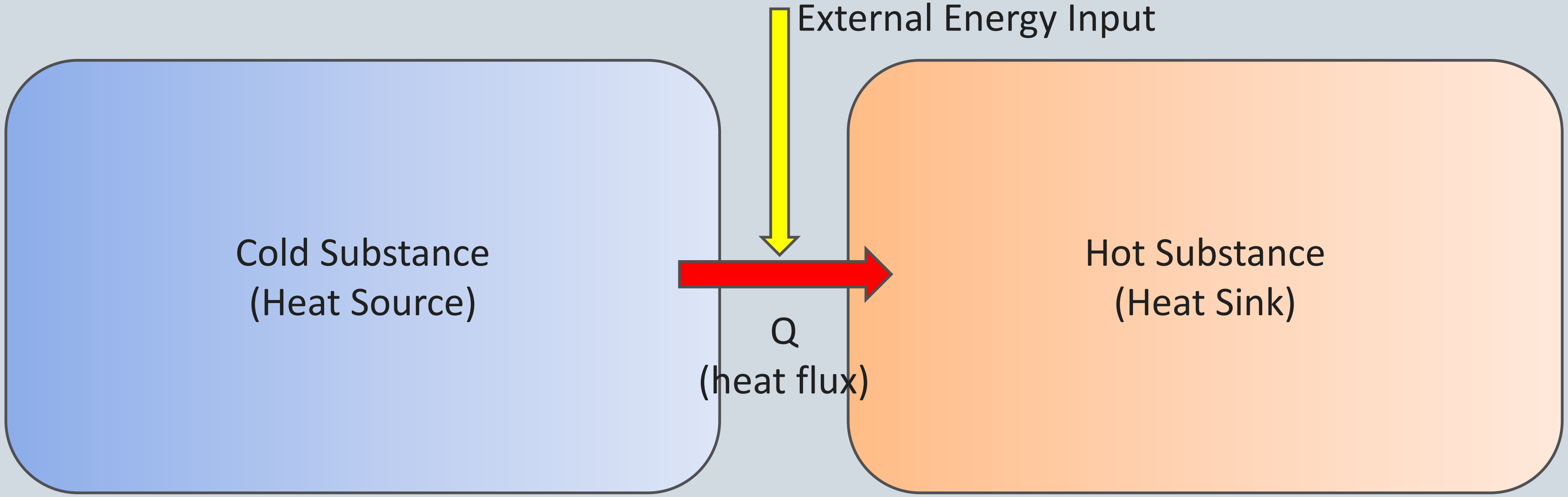
Limit of Technology:

Evaporative cooling cannot cool wastewater below the wet bulb temperature of the ambient air.

$$T_{effluent} > T_{wetbulb}$$

Mechanical Cooling

Heat energy is transferred from areas of low temperature to areas of higher temperature (Trying to cheat nature)



$$Q = COP_{chiller} * W_{external}$$

$COP_{chiller}$ = coefficient of performance, varies based on technology and heat sink temperature

$W_{external}$ = external energy input

Mechanical Cooling

In WQCD's feasibility document,

"Mechanical Cooling", "Heat Pump", and "Chiller" mean the same thing:

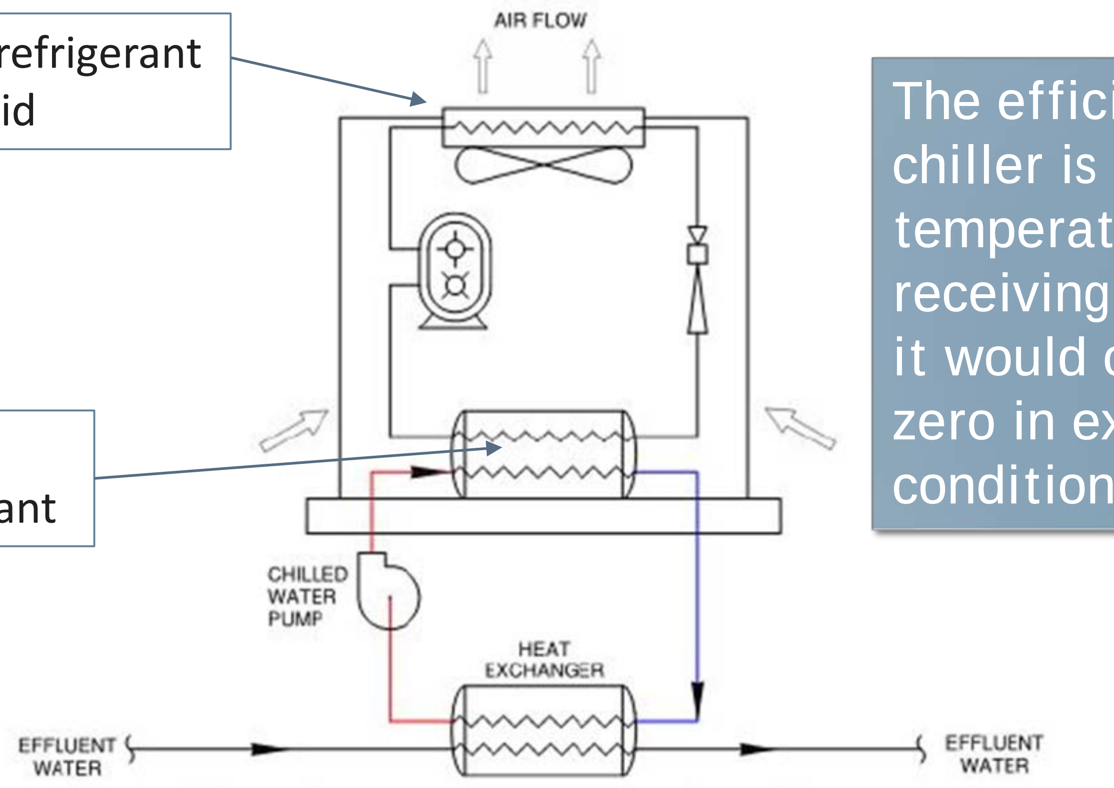
Heat energy is transferred in the opposite direction of natural heat flow

Type of Heat Pump	How it works	Common places to find it
Vapor-compression refrigeration	Driven by external electricity	Almost any refrigerator
Absorption refrigeration	Driven by external heat	Places with waste heat or cheap fuel
Thermoelectric	Relation between heat flux and voltage	Laboratory
Thermoelastic	Change in internal energy due to stretching	Laboratory
Thermoacoustic	Driven by controlled pressure waves	Laboratory
Thermomagnetic	Driven by external magnetic field	Laboratory

Mechanical Cooling

Example: Air-cooled Chiller (vapor compression) – electricity used to drive process

Heat is dumped when refrigerant is compressed to a liquid



Heat is taken up by evaporating refrigerant

The efficiency of a chiller is affected by the temperature of the receiving sink,
it would only approach zero in extreme conditions

Mechanical Cooling

Limit of Technology:

Mechanical cooling would only be technologically limited in extreme situations.

$$T_{effluent} > T_{freezing}$$

Estimating Environmental Impacts

- Primary impact associated with impacts from electric use
- Study assumes electricity is purchased from the grid, impacts are **indirect**
- Region-specific multipliers applied to electric use values, USEPA eGRID2014

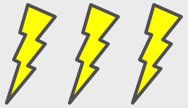
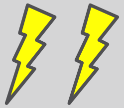
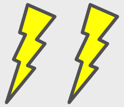
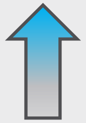
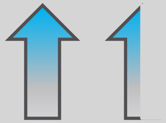
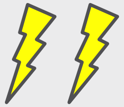
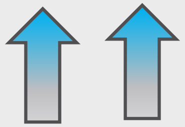
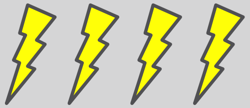
carbon dioxide: 1737.7 $lbCO_2$/MWh

- Water loss and PM_{10} calculations are **direct** impacts from the plant site
- Other waste issues qualitatively identified, e.g. refrigerant disposal

Technologies Analyzed in Study

- Transfer heat to a colder material (natural heat flow)
    1. Heat exchanger using surface water for cooling
    2. Effluent blending with deep groundwater
    3. Ground loop exchanger/geothermal cooling
- Evaporative cooling (energy transfer by heat of vaporization)
    4. Passive cooling pond
    5. Spray pond
    6. Cooling tower
- Mechanical cooling (trying to cheat nature)
    7. Chiller using traditional vapor-compression cooling

Generalized Findings

Technology	Capital Cost	Energy Usage	GHG SO_x NO_x Emissions	Onsite PM_{10} Emissions	Water Loss
1. Heat Exchanger Using Surface Water	$				
2. Blending with Deep Groundwater	$$				
3. Ground loop exchanger/ geothermal cooling	$$$$				
4. Cooling Tower	$$				
5. Passive Cooling Pond	$$$				
6. Spray Pond	$$				
7. Chiller	$$				

Innovative, Hybrid & Combo Approaches

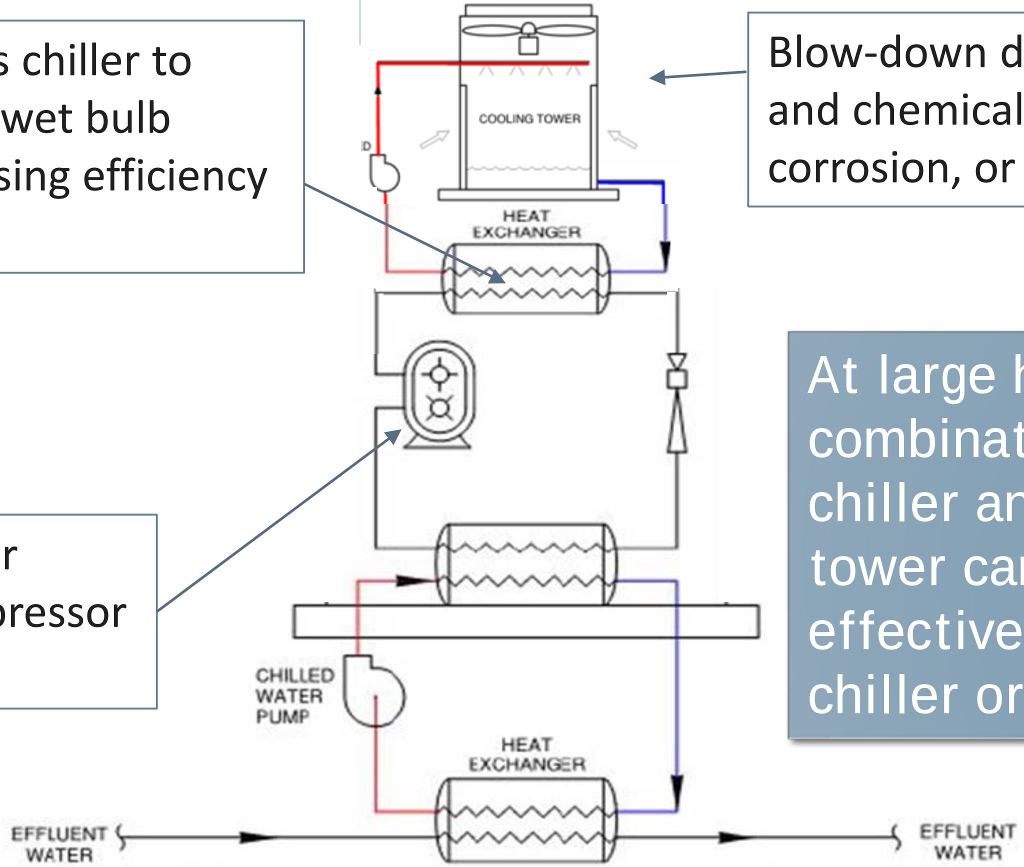
The guidance document discussed these options in more qualitative fashion:

- Chiller with Closed Loop Cooling Tower or Other Cooling Water Source
- Other Combinations and Hybrids
- Retractable Solar Shades
- Use of High Efficiency Motors and Energy Efficient Designs
- Alternate Electric Sources
- Energy Recovery and Reuse
- Absorption Refrigeration
- Energy Recovery & Mechanical Cooling

Chiller with Closed-Loop Cooling Tower

Cooling tower allows chiller to discharge heat near wet bulb temperature, increasing efficiency (i.e. higher COP)

Blow-down discharge, make-up water, and chemicals to prevent scale, corrosion, or biogrowth will be required



More efficient chiller allows smaller compressor and less electric use

At large heat loads, the combination of a smaller chiller and smaller cooling tower can be more cost effective than a stand-alone chiller or cooling tower.

Other Combinations and Hybrids

Countless combinations and hybrids of the basic heat transfer mechanisms exist.

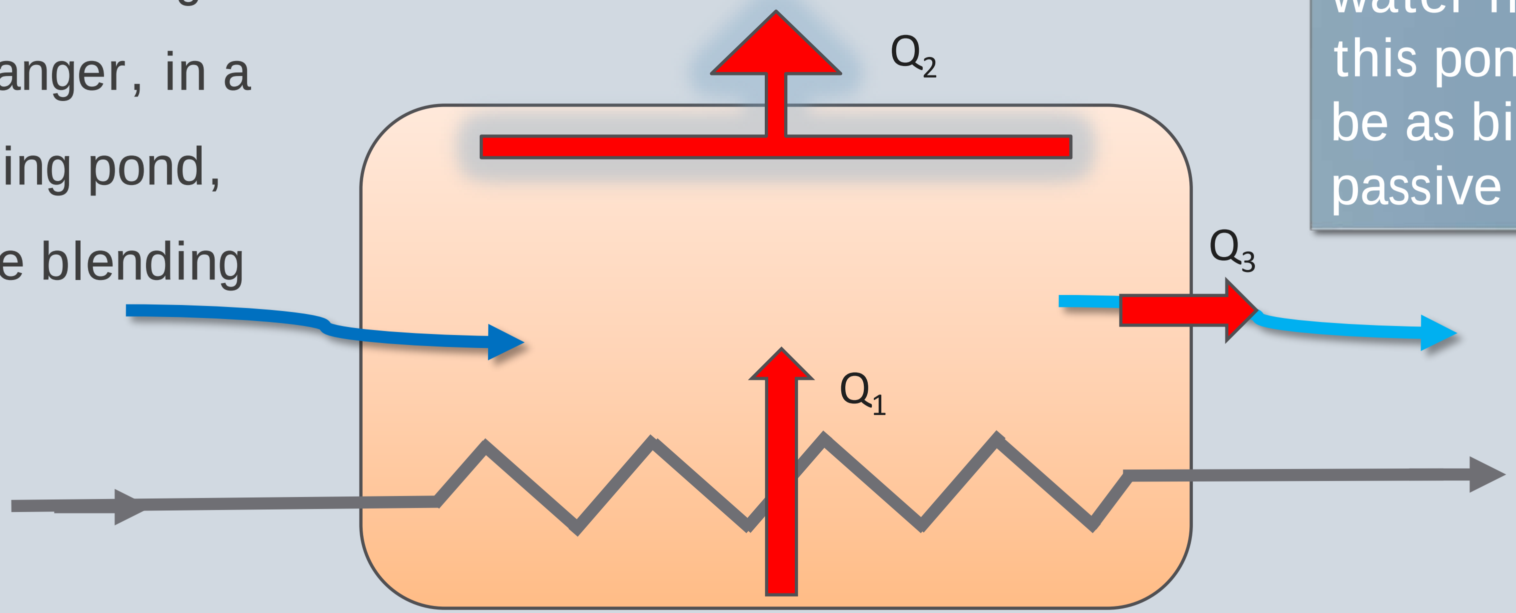
Example:

Pipe-in-pond cooling is …

a heat exchanger, in a

passive cooling pond,

with possible blending



Unless there is colder water flowing through this pond, it will need to be as big as a standalone passive cooling pond.

$$Q_1 = Q_2 + Q_3$$

Retractable Solar Shades

Minimizing incoming solar radiation while maintaining as much outgoing long-wave (e.g. infrared) radiation as possible may have a measureable impact on effluent temperatures

Energy Transfer Phenomena	Temperature change ^{o}C/day
Short-wave radiation [net incoming solar radiation]	+ 0.5 to 2.5
Long-wave radiation [net outgoing blackbody radiation]	- 0.5 to 1.0
Sensible heat [heat transferred to the air and through aeration]	+/- 0.5 to 3.5
Evaporation	- 0.5 to 2.5
Process energy [energy released from biological reactions]	+ 0.5 to 2.0
Mechanical energy [heat from blower inefficiency/friction losses]	+ < .1
Geothermal energy [heat transferred to ground through basin walls]	+/- <0.05
Precipitation, rain/snow at surface	+/- <0.2

Typical Range of Contributions, Temperature Changes in Treatment Plants

Reproduced from la Cour Jansen et al., 1992

Minimizing Electric Use Impacts

Impact of electric use is based on two components:

Impact = Amount of electricity used * Impact per unit electric use

Two ways to minimize impact: reduce use or find alternate source with less impact:

1. **Use of High Efficiency Motors and Energy Efficient Designs**
2. **Alternate Electric Sources**

These are not standalone alternatives,

but rather a hybrid or combination of other technologies

Adding high efficiency motors and solar generators to an air-cooled chiller can significantly minimize environmental impacts, however, it will increase capital costs (operating costs may go down).

Energy Recovery and Reuse

Thermal energy in wastewater can be recovered using a similar system as a residential heat pump (note, this is a chiller):

- Energy must be transported in a fluid such as air or water
- Low grade heat sufficient for space heating, snow melting, and other limited use
- Most attractive if installed at point of demand, e.g. throughout collection system

Chemical energy can be recovered as methane from anaerobic digesters

- Combined Heat and Power (CHP), aka Co-Gen, uses biogas to produce heat and electricity

Absorption Refrigeration

Absorption Refrigeration is a mechanical cooling option that is powered by external heat.

Use of an anaerobic digester and a co-gen system allows two options for powering a chiller with recovered energy:

1. Electricity generated from biogas can be used to power a vapor compression chiller
2. Heat generated from biogas can be used to power an absorption refrigerator

Facility-wide energy balance may be appropriate to determine best use of biogas

This is overly detailed and I will it pare back

Energy Recovery & Mechanical Cooling

Example: Combined heat and power (CHP) potential for cooling from literature values

5 MGD Example Facility with new CHP Process	
Cooling Load	1830 kW
Electricity from CHP	130 kW
Usable Heat from CHP	146 kW
Current Electric use	500 kW

Comparison of Mechanical Refrigeration Options		
	Vapor Compression Refrigeration	Absorption Refrigeration
Capacity	1830 kW	1830 kW
COP	3.3	1.8
Electric Req'd	548 kW	-
Amount from CHP	24%	-
Heat Req'd	-	1020 kW
Amount from CHP	-	14%

Based on medium to low strength waste – high strength waste will boost CHP production

CHP can be used year round – how do these numbers balance over a year of operation?

Next Steps

Findings of Feasibility Study beg many questions

- Are these technologies in the realm of feasibility?
- Are the proven and reliable technologies (cooling towers and chillers) sustainable?
- What is the most sustainable approach to recovering energy from wastewater?
- How does sustainable energy use and recovery fit in with cooling wastewater to improve aquatic habitat and minimize other environmental impacts?
- How does all this fit in with the “other consequences” criterion?

Next Steps

A complete feasibility analysis requires multiple steps.

1. Sizing, costing, and estimating output rate of environmental pollutants is relatively straightforward and objective.
2. Weighing the relative impacts of each alternative is highly subjective.

The feasibility study provides a solid foundation of the objective. From here, we begin the strange adventure into the subjective…

Engaging stakeholders such as EPA and individual dischargers will be critical and is underway.

Landmine alert!
How many miles of aquatic habitat should be allowed to be impacted to save a ton of greenhouse gas emissions?

Questions and Discussion

"It is better to know some of the questions than all of the answers." – James Thurber

Feasibility Study Results (5 MGD, 2 ºC Temperature Reduction)

Technology	Capital Cost (2017 USD)	Energy Usage (kWh/mo)	GHG Emissions (Tons CO_2e/mo)	PM_{10} Emissions (lb/mo)	Water Loss (MG/mo)
1. Heat Exchanger Using Surface Water	278,737	25399	22	0	0
2. Blending with Deep Groundwater	756,675	367504	321	0	0
3. Ground loop exchanger/ geothermal cooling	1,849,000	55026	48	0	0
4. Cooling Tower	1,380,669	0	0	0	1.4
5. Passive Cooling Pond	305,216	38885	34	12000	2.76
6. Spray Pond	507,000	42801	37	41	0.5
7. Chiller	860,000	391250	342	0	0