Dissolved oxygen modeling in Mid Coast Rivers

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Oregon Department of Environmental Quality

Mid Coast Implementation Ready TMDL
Local Stakeholder Advisory Committee Meeting
July 15, 2015
Newport, Oregon

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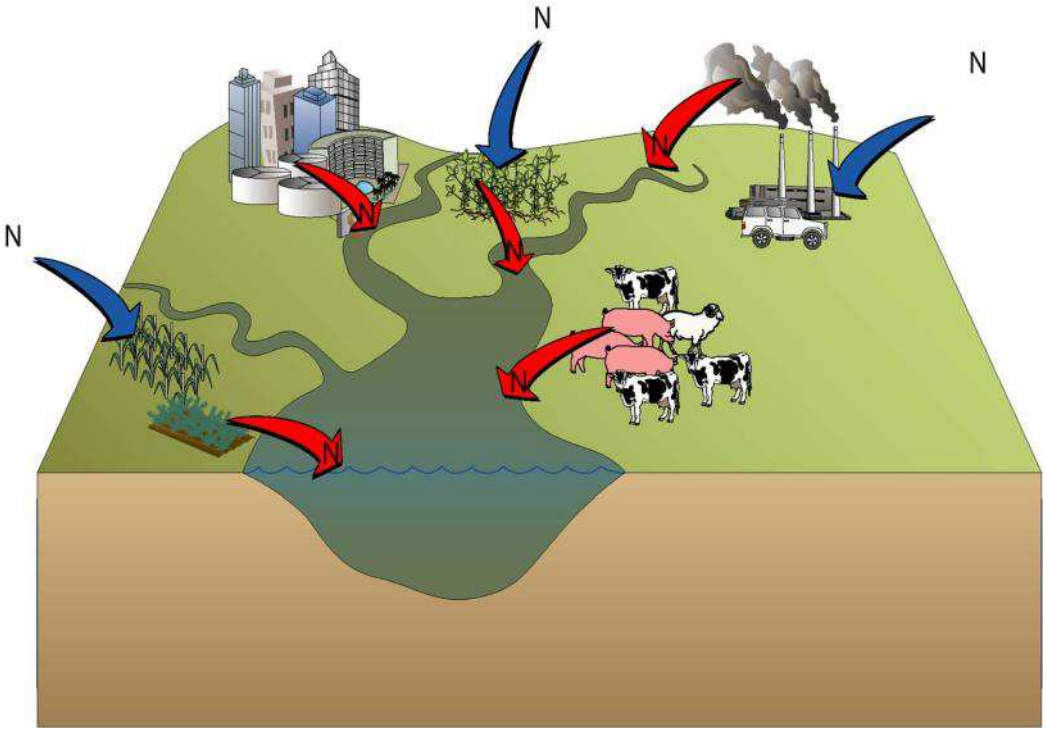
- Listings for DO on the Mid Coast need to be addressed
- Linked to other water quality issues (i.e., temperature)
- Data from DEQ & watershed councils available for modeling

Talk outline

- TMDL process
- Background on dissolved oxygen
- Dissolved oxygen TMDLs in Oregon
- Dissolved oxygen in the Mid Coast
- Next steps

Total Maximum Daily Load (TMDL)



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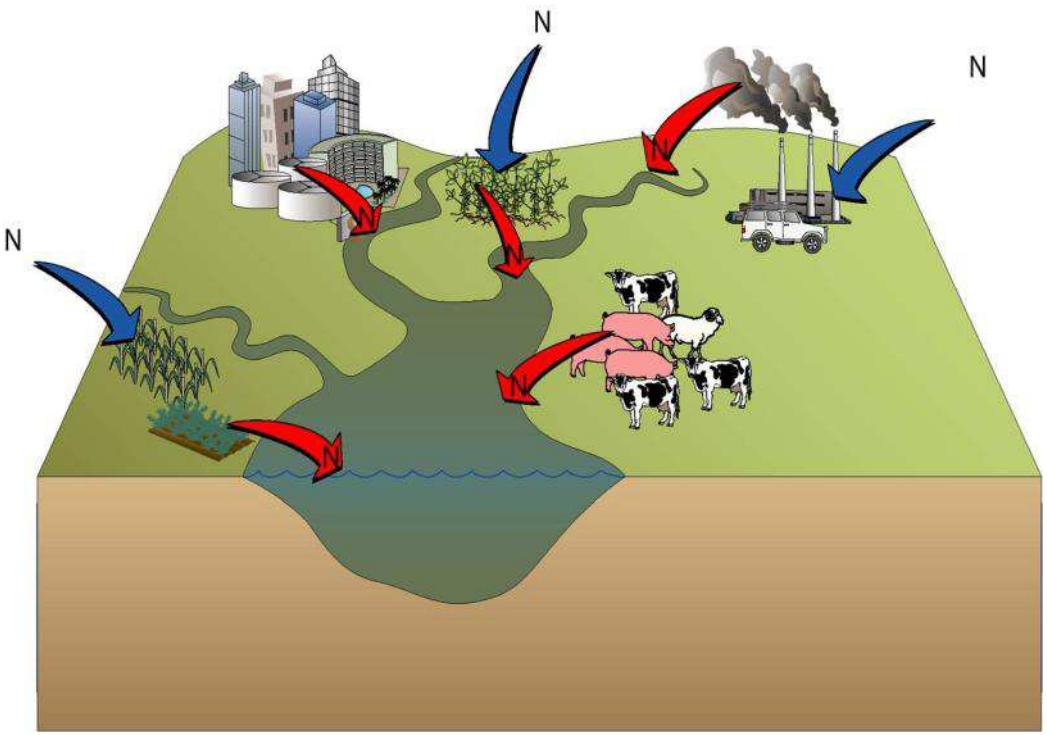

- Pollution a water body can receive before impairment

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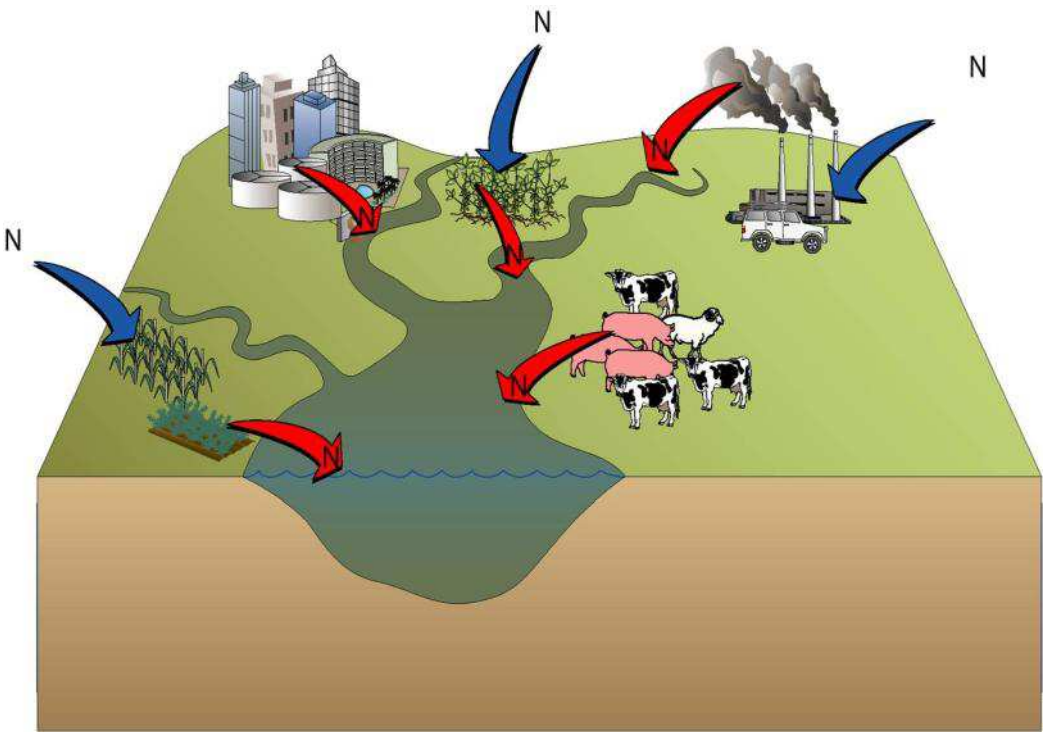


- Pollution a water body can receive before impairment
- Required when a water quality standard exceeded

TMDL equation

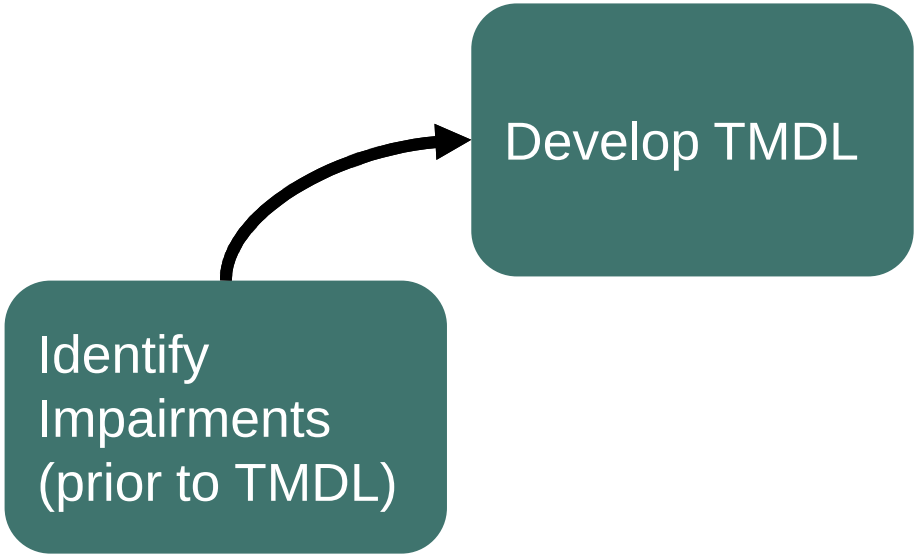
$$TMDL = LA + WLA + MOS + RC$$

- LA: Load Allocation (nonpoint sources)
- WLA: Waste Load Allocation (point sources)
- MOS: Margin of Safety (account for uncertainty)
- RC: Reserve Capacity (set aside for future development)

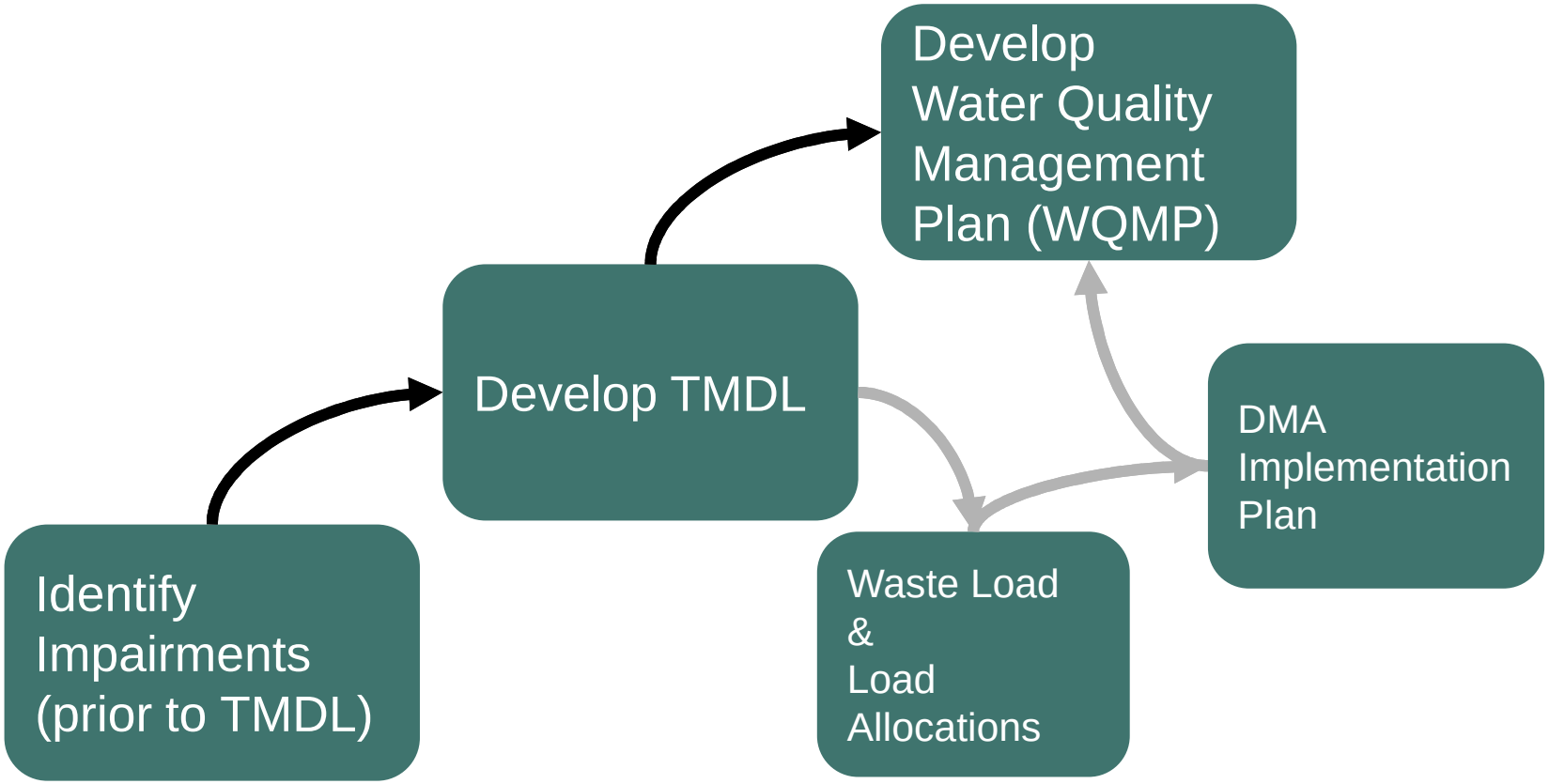
TMDL process

Identify Impairments (prior to TMDL)

TMDL process



TMDL process



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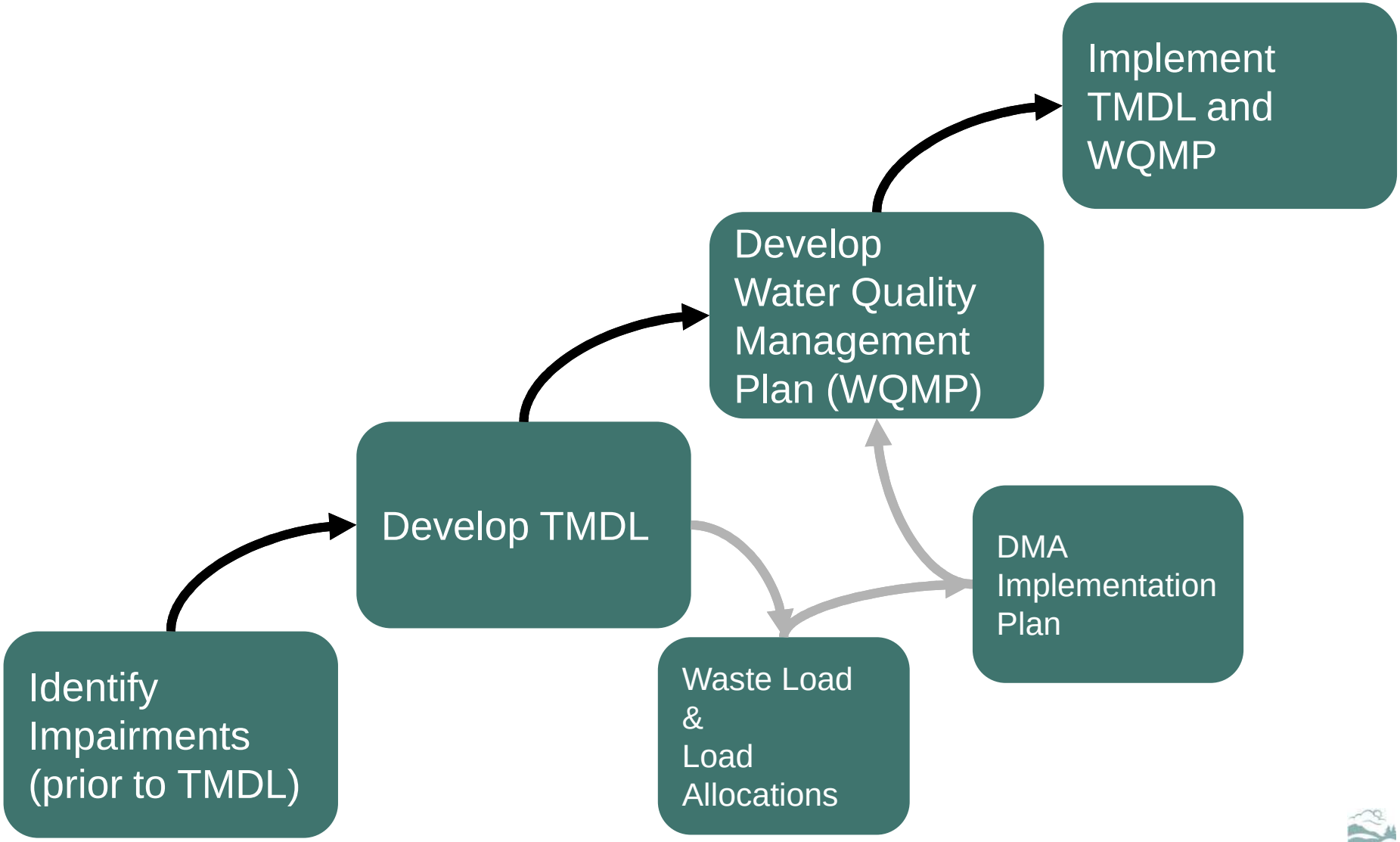
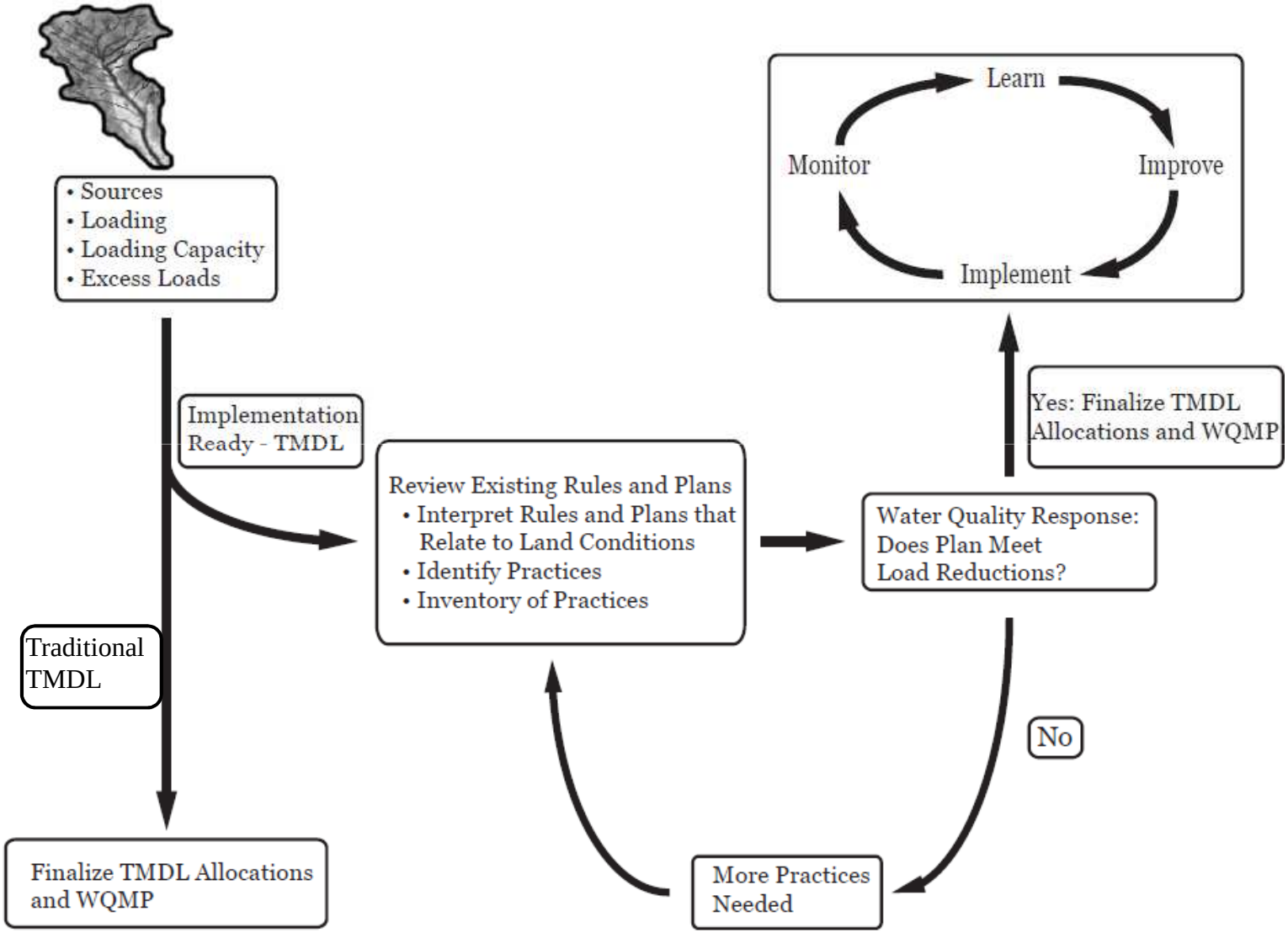


Traditional TMDLs vs. Implementation-Ready TMDLs



Background on dissolved oxygen

Photo by Bonnie Lamb

Dissolved oxygen (DO) in rivers and streams

- A fundamental water quality parameter
- Essential to metabolism of aerobic organisms
- Influences solubility of nutrients, metals, and metalloids

Photo by Russ George

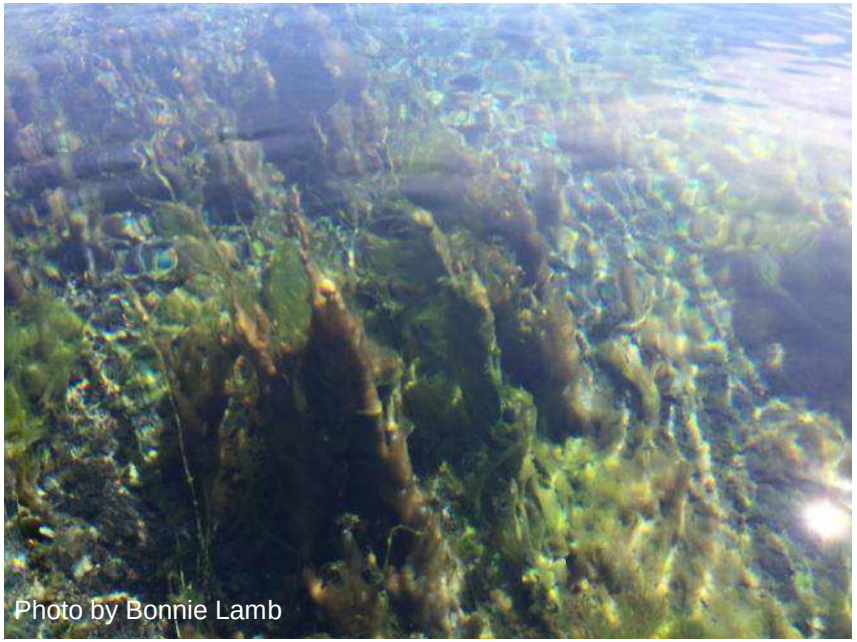
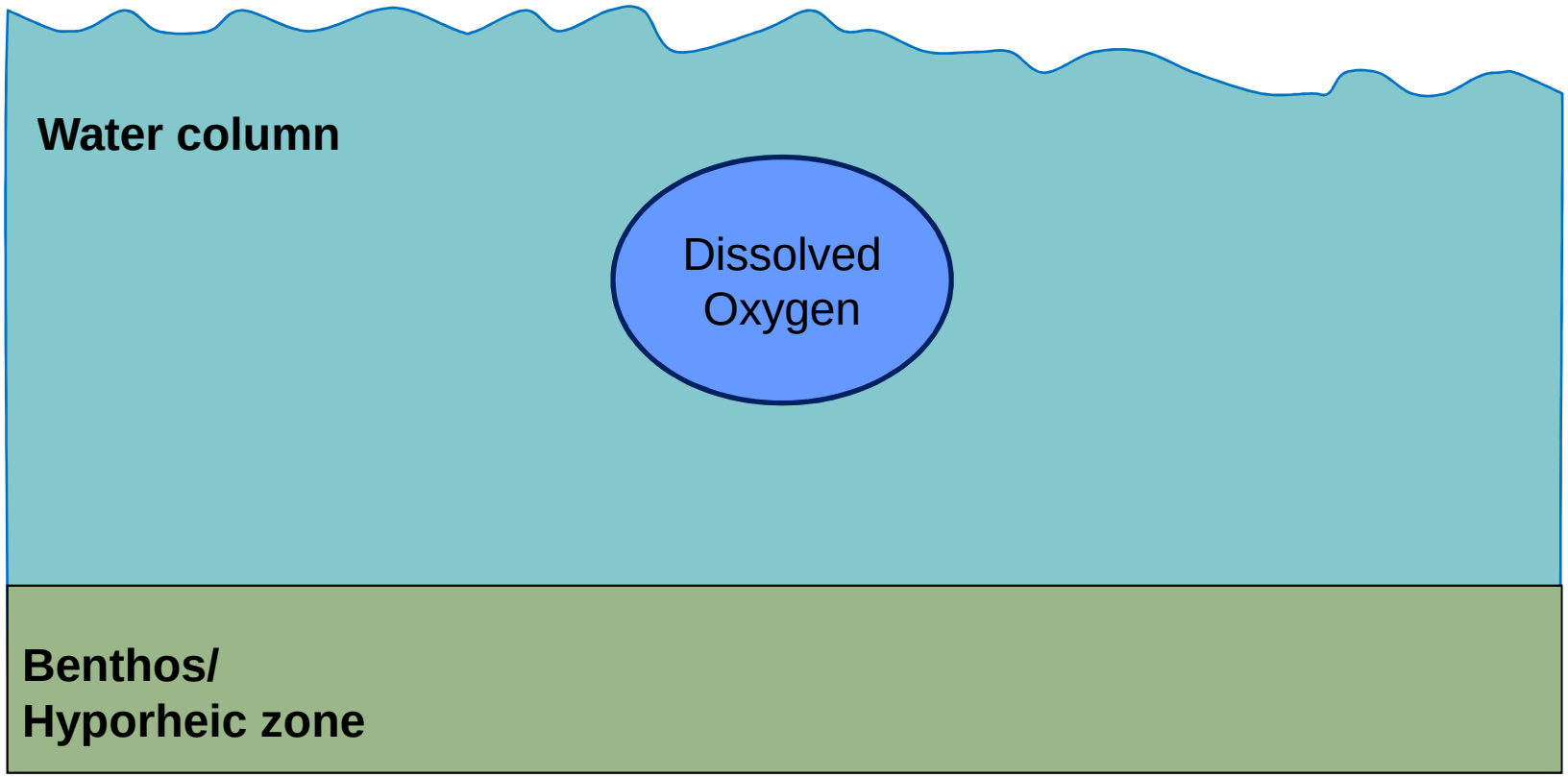


Photo by Bonnie Lamb

Conceptual model



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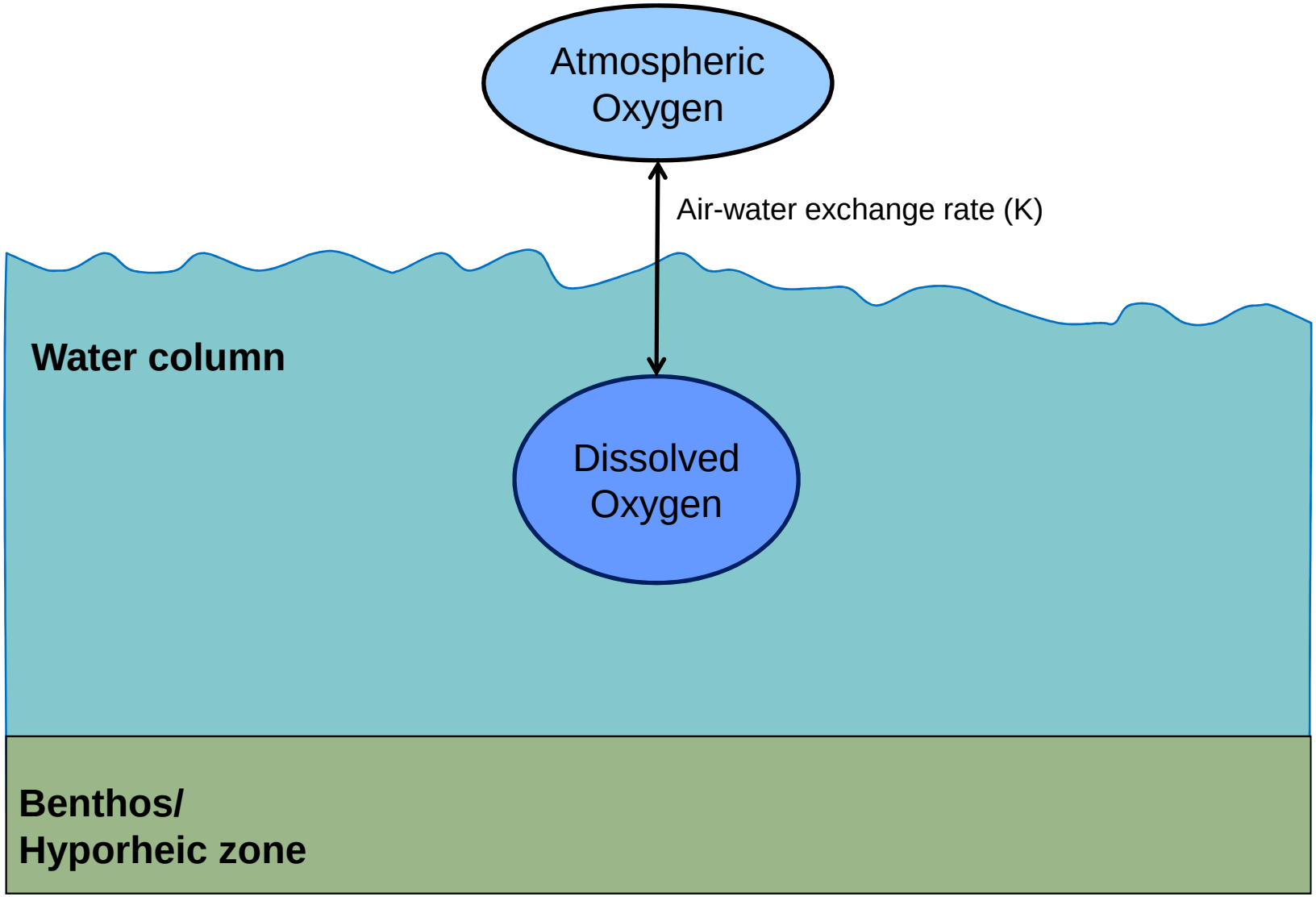

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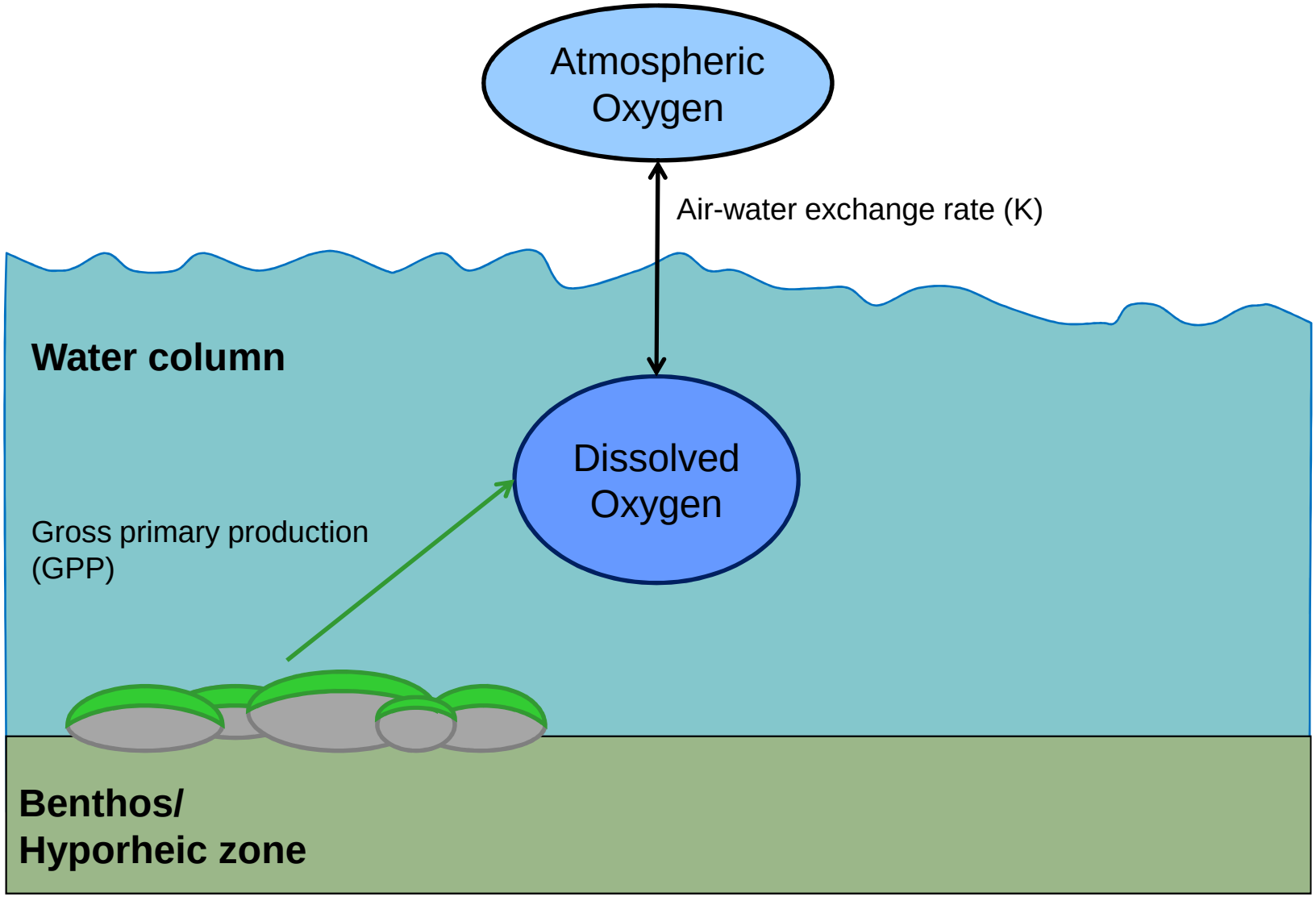

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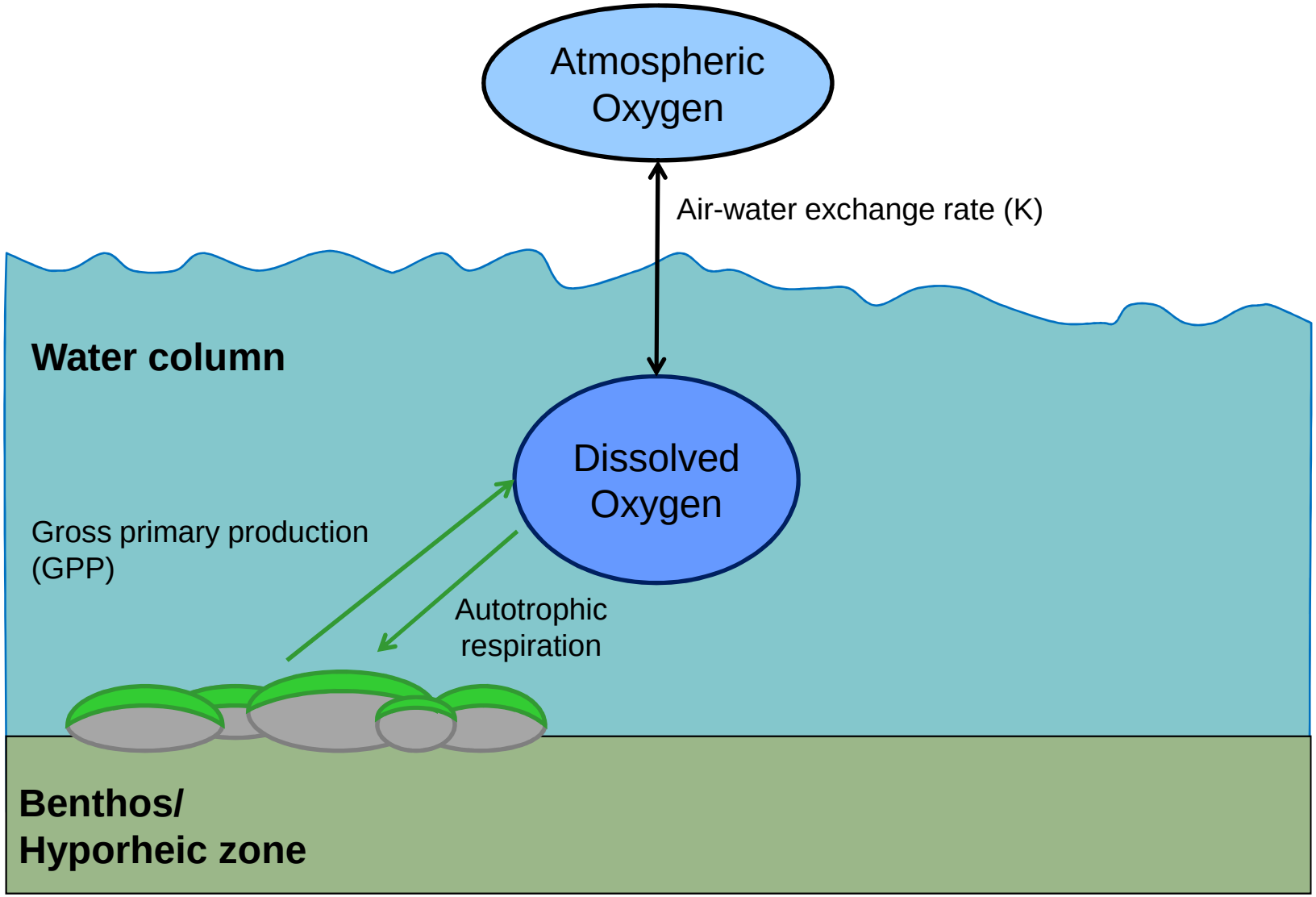

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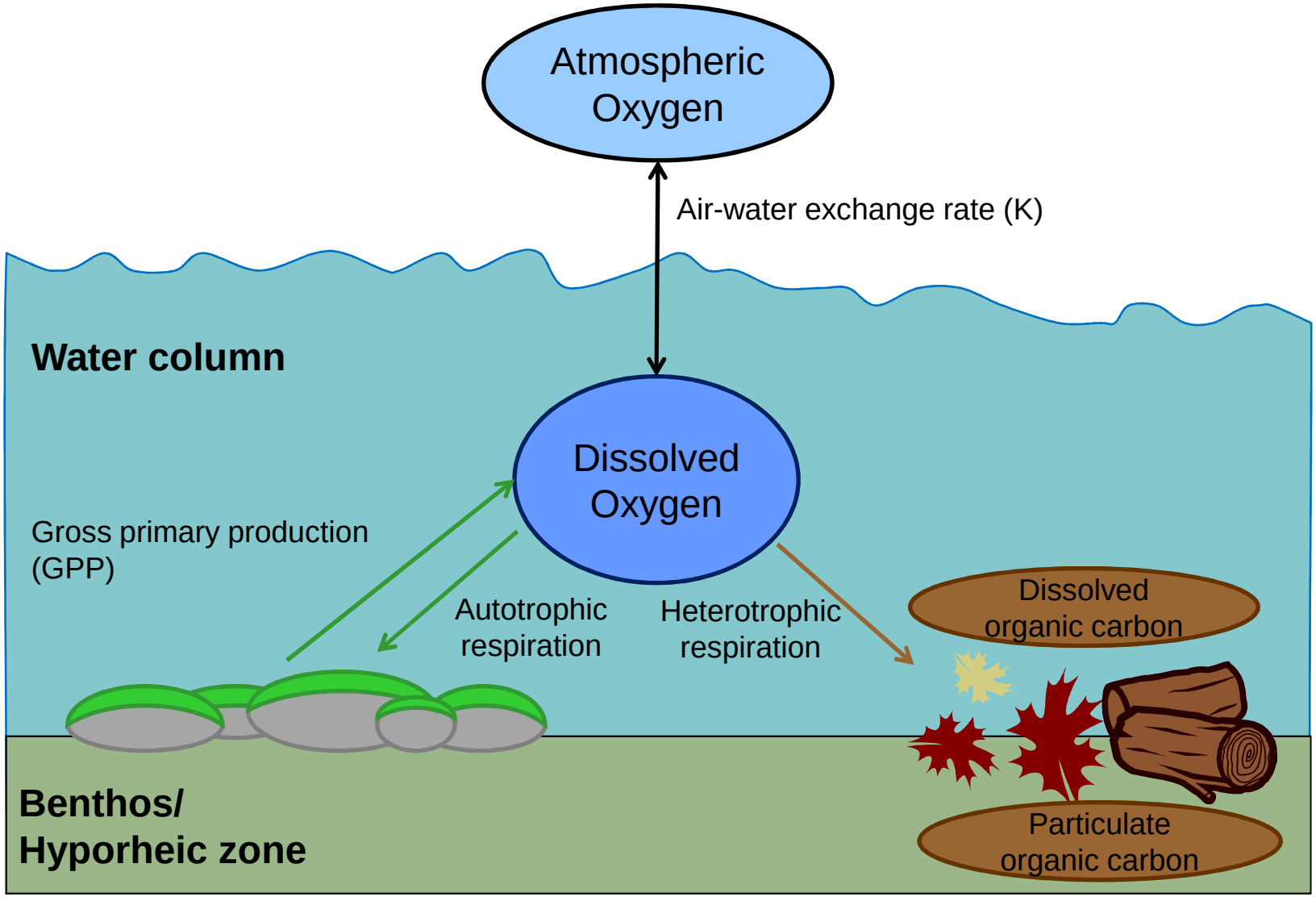

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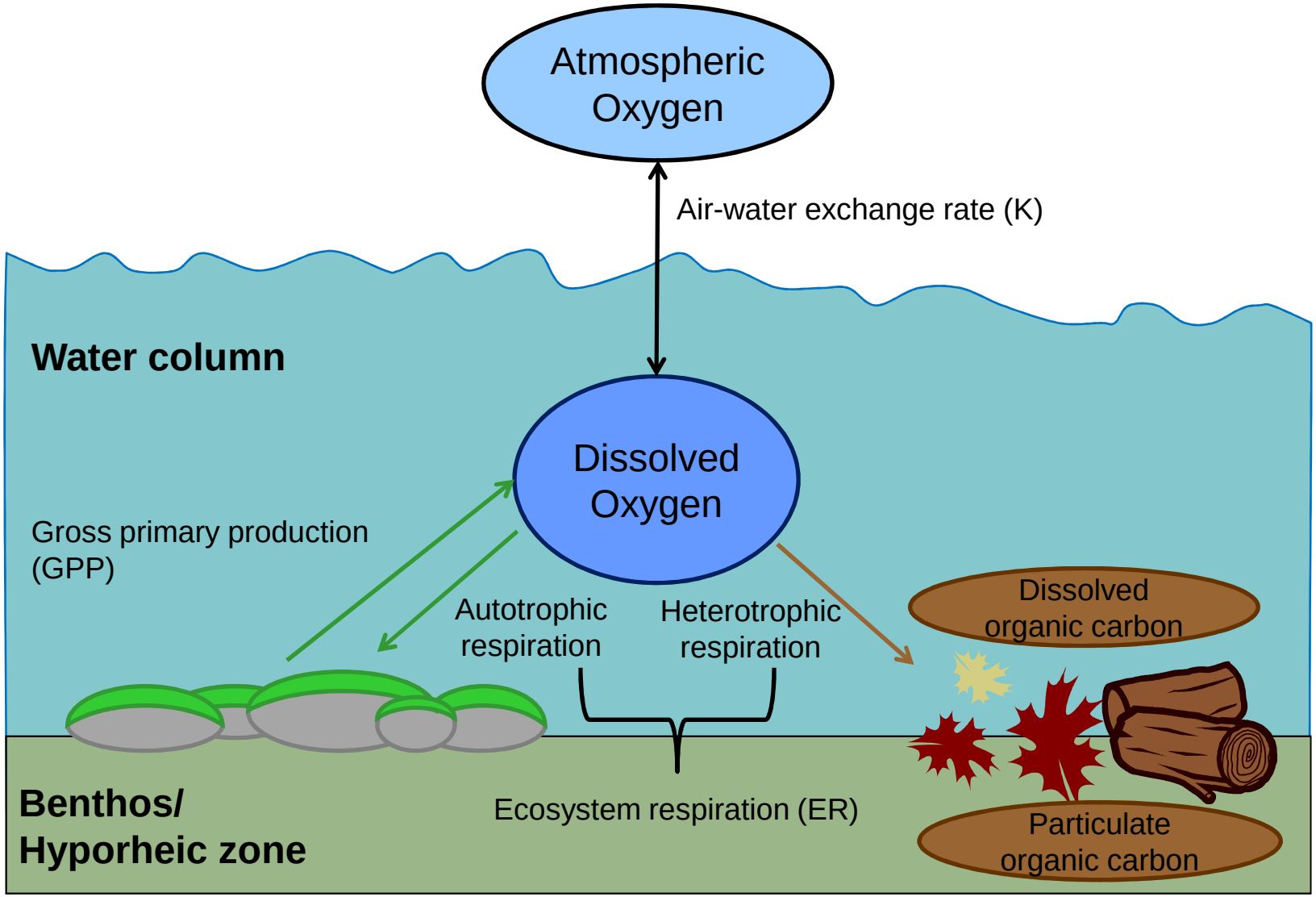

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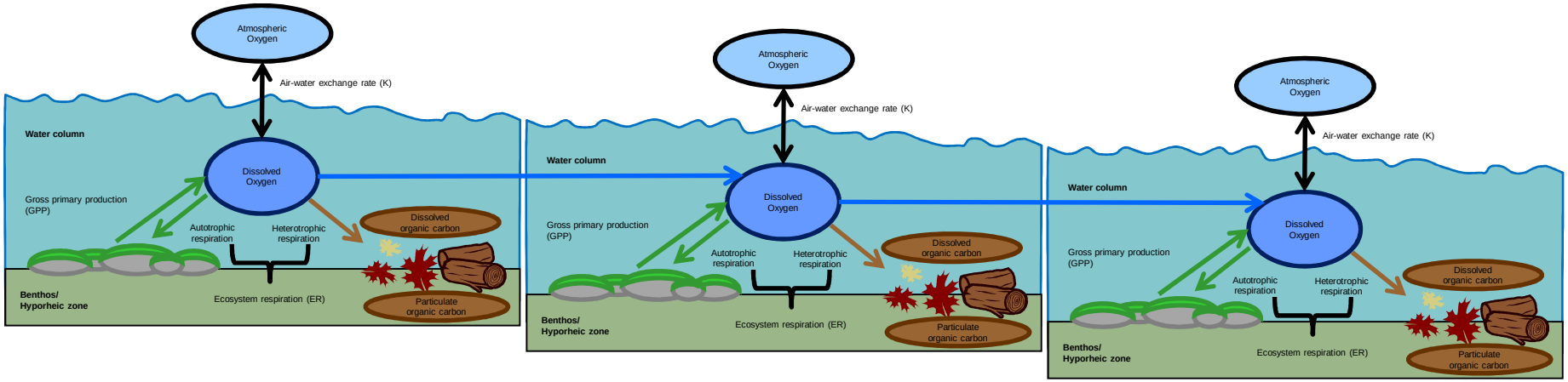
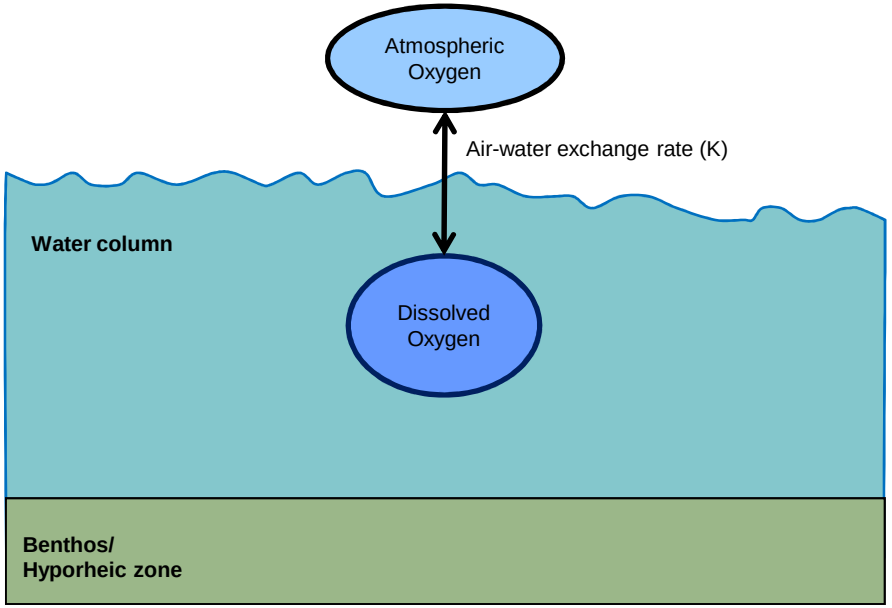


DO point measurements are combination of local <u>and</u> upstream influences

Take home messages

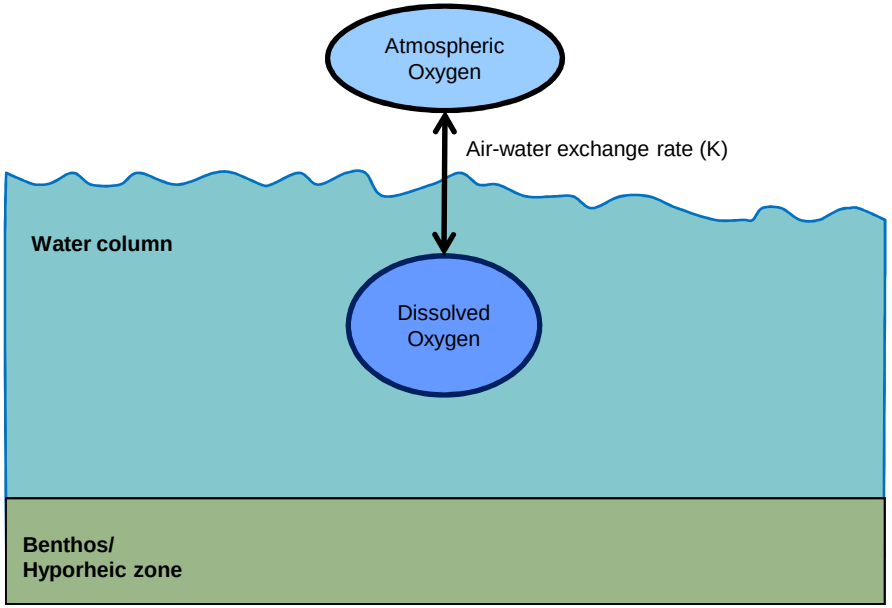
- Air-water exchange: adds or subtracts DO
- Gross Primary Production (GPP): adds DO
- Ecosystem Respiration (ER): subtracts DO

What influences air-water exchange rate?



What influences air-water exchange rate?

- Increases with temperature



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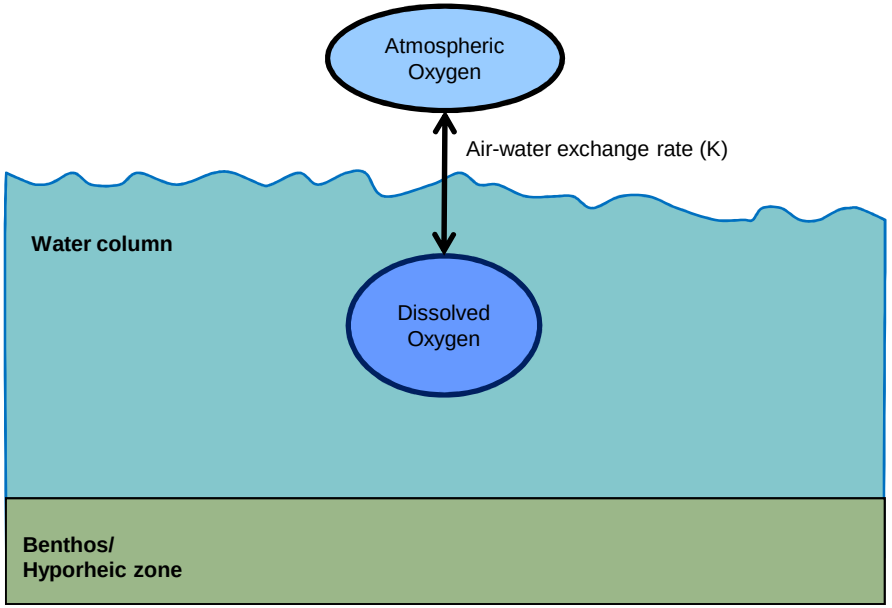
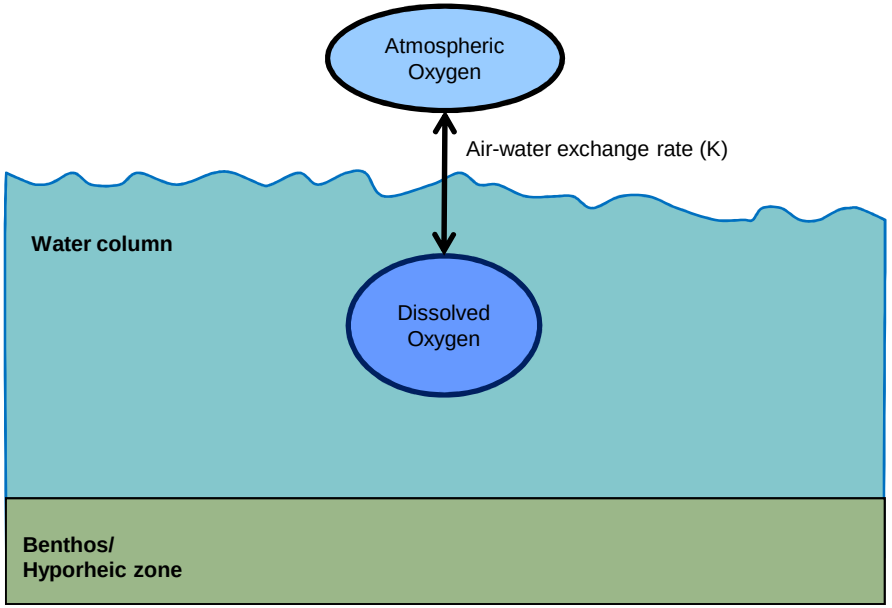
- Decreases with barometric pressure (elevation)



What influences air-water exchange rate?

- Increases with temperature
- Decreases with barometric pressure (elevation)
- Increases with channel roughness & slope



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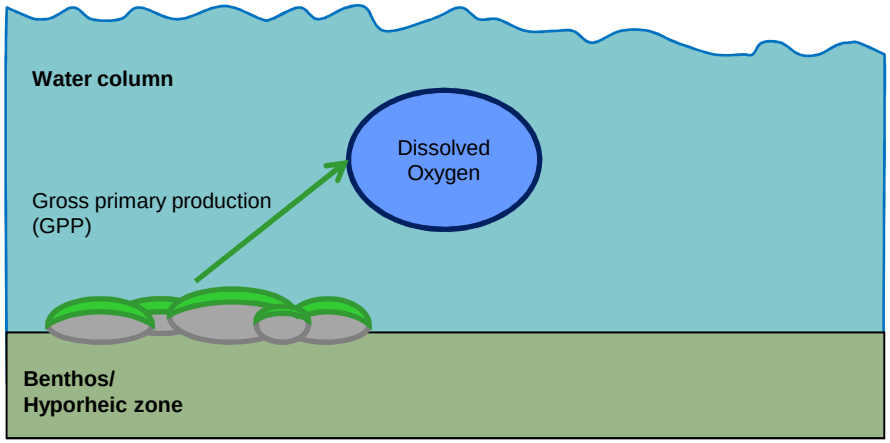

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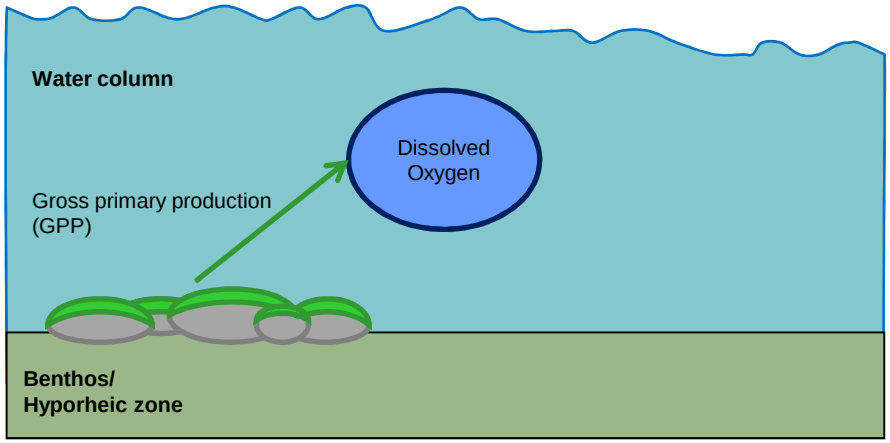
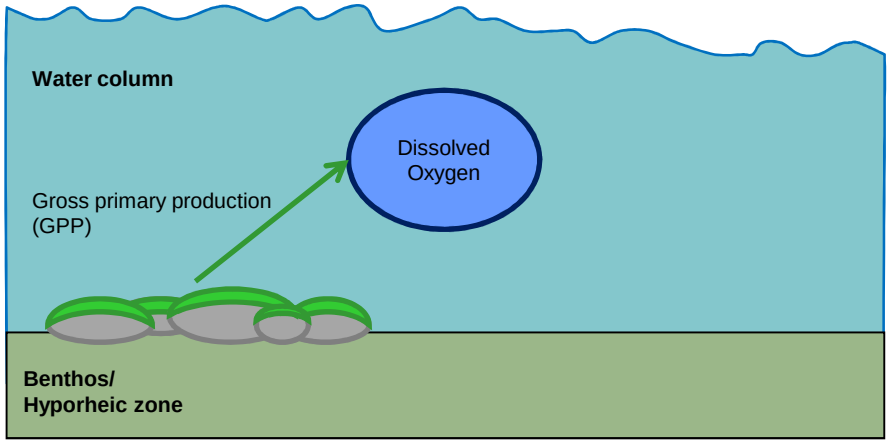


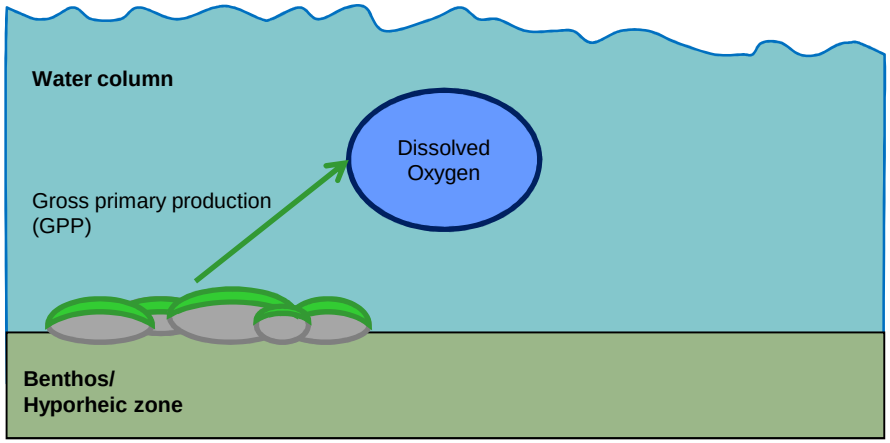
What influences gross primary production (GPP)?

- Increases with temperature
- Increases with light



What influences gross primary production (GPP)?

- Increases with temperature
- Increases with light
- Increases with nutrients



What influences Ecosystem Respiration (ER)?

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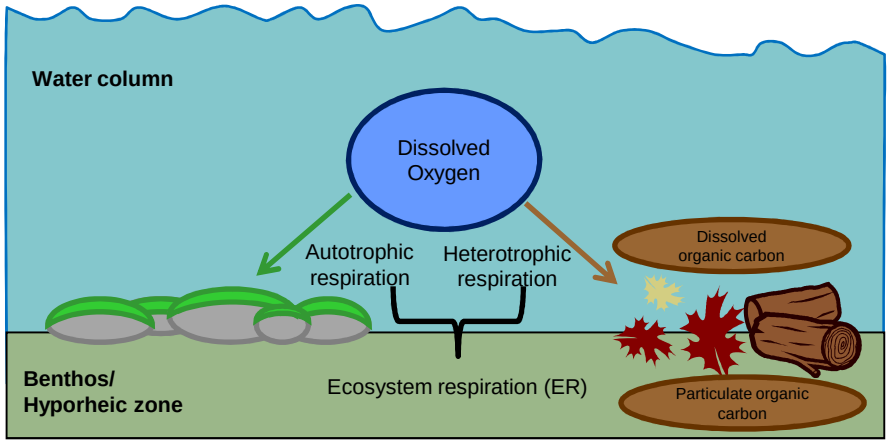

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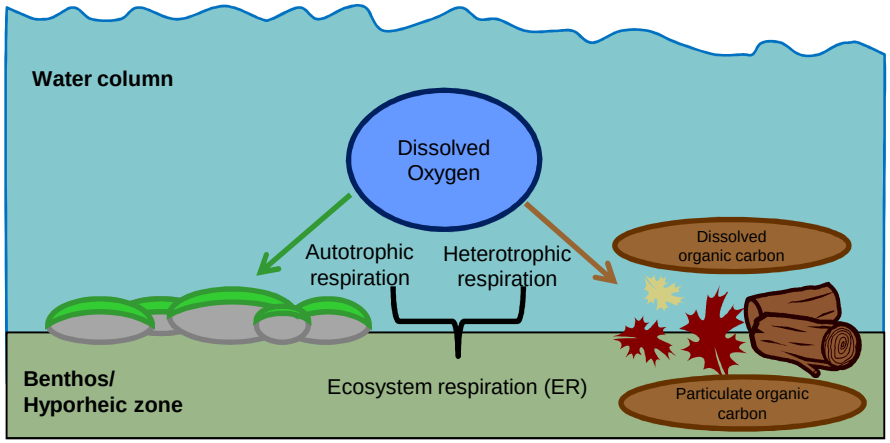

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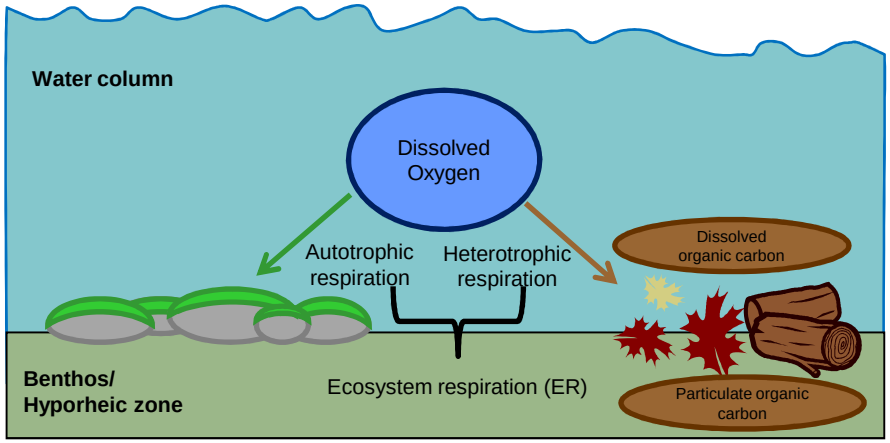
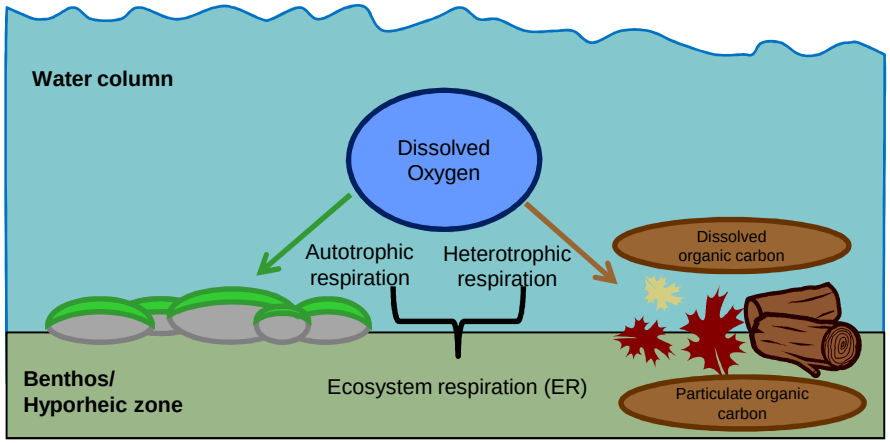


What influences Ecosystem Respiration (ER)?

- Increases with temperature
- Increases with GPP
- Increases with nutrients
- Increases with organic matter standing stock

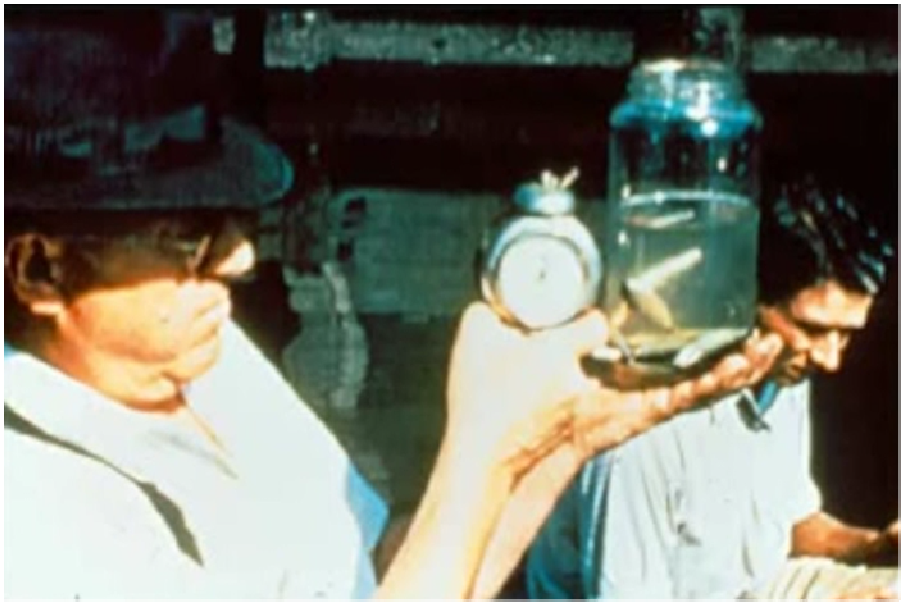


Dissolved oxygen TMDLs in Oregon

Photo by Shannon Hubler

History of DO issues in Oregon rivers and streams

- Low DO prevalent in the Willamette River in early 1900s



Willamette: A River Restored

- Helped spur Water Purification and Prevention of Pollution Bill and creation of State Sanitary Authority (1938)

State criteria for DO in rivers and streams

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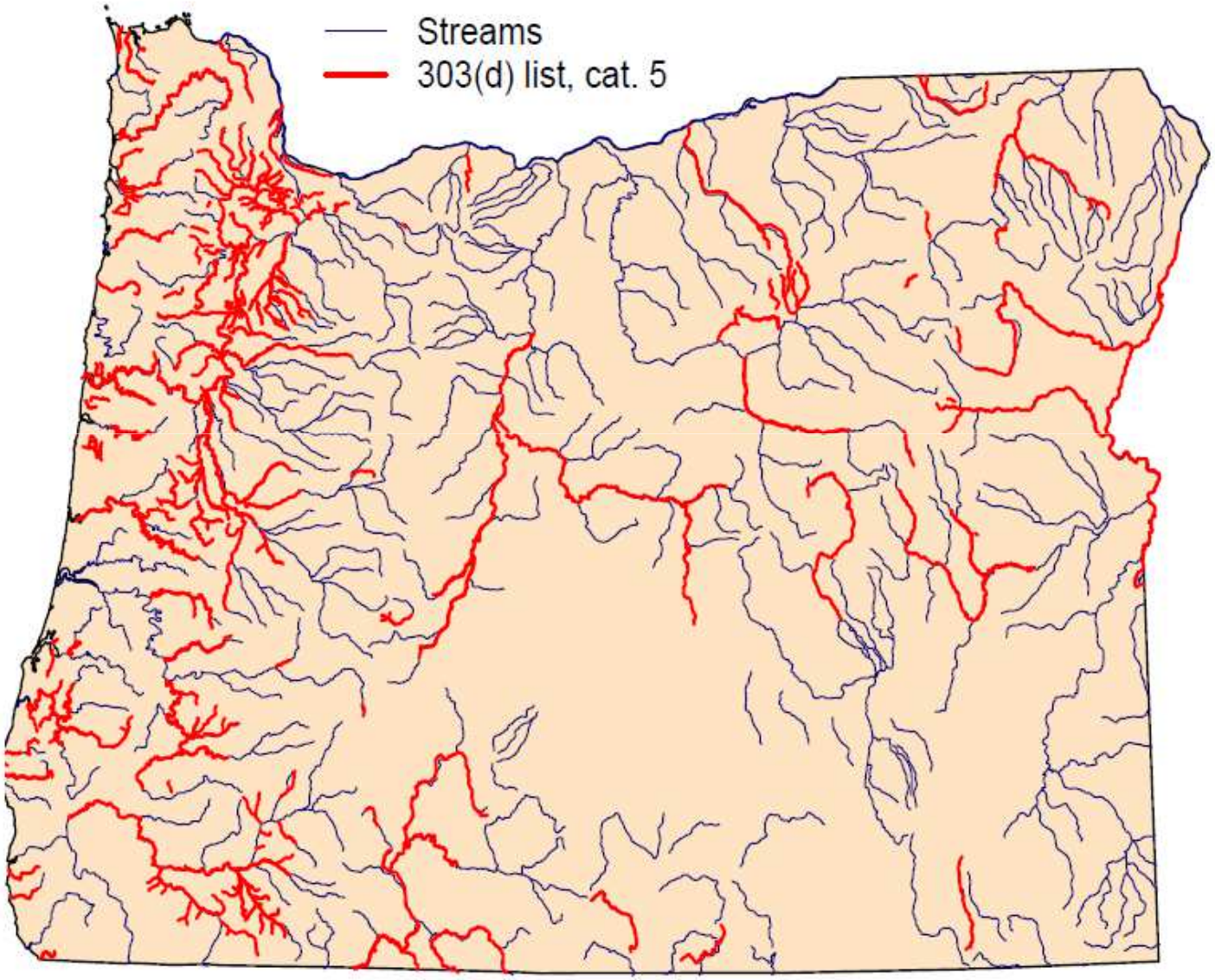
Habitat Type	Criteria	Considered in TMDL Analysis
Spawning	≥ 11.0 mg/L or ≥ 95% saturation	If minimal intergravel DO is ≥ 8.0 mg/L (spatial median), then criterion is ≥ 9.0 mg/L
Cold Water	≥ 8.0 mg/L or ≥ 90% saturation	With adequate data, can be ≥ 8.0 mg/L (30-day mean), ≥ 6.5 mg/L (7-day mean), or ≥ 6.0 mg/L minimum
Cool Water	≥ 6.5 mg/L	With adequate data, can be ≥ 6.0 mg/L (30-day mean), ≥ 5.0 mg/L (7-day mean), or ≥ 4.0 mg/L minimum
Warm Water	≥ 5.5 mg/L	With adequate data, can be ≥ 5.5 mg/L (30-day mean or ≥ 4.0 mg/L minimum

OAR 340-041-0016

DO listings in Oregon rivers (2010 Integrated Report)



Approach for DO TMDLs in Oregon

- LA and WLA developed for pollution influencing DO
  - Biochemical Oxygen Demand
  - Nutrients
  - Light
  - Temperature

EPA-approved DO TMDLs for Oregon rivers

Water Body	Year Approved	Pollutant(s)	Model Used
Tualatin River	1988, 2001 & 2012	Ammonia, Phosphorus & Temperature	CE-QUAL-W2
Bear Creek (Rogue)	1992	Ammonia & Biochemical Oxygen Demand	Statistical
Pudding River	1993	Ammonia & Biochemical Oxygen Demand	QUAL2E
Rickreal Creek	1994	Biochemical Oxygen Demand	QUAL2E
Coast Fork Willamette River	1996	Ammonia & Phosphorus	Mass Balance
Coquille River	1996	Biochemical Oxygen Demand	DYNHYD5-WASP4
Columbia Slough	1998	Phosphorus & Biochemical Oxygen Demand	CE-QUAL-W2
Upper Grande Ronde River	2000	Temperature, Sediment, Nitrogen & Phosphorus	PCM
Sprague River	2002	Temperature	QUAL2E
Snake River – Hells Canyon	2004	Phosphorus	Mass Balance
Amazon & Coyote Creeks	2006	Temperature	CE-QUAL-W2 & PCM
South Umpqua River	2007	Temperature & Nutrients	QUAL2Kw
Upper John Day River	2010	Heat, Flow, & Morphology	Statistical
Malheur River	2010	Phosphorus	Mass Balance

http://www.deq.state.or.us/WQ/TMDLs/approved.htm

DO in Oregon's Mid Coast Rivers

Photo by Ryan Michie

State criteria for DO in rivers and streams – Relevant for the Mid Coast

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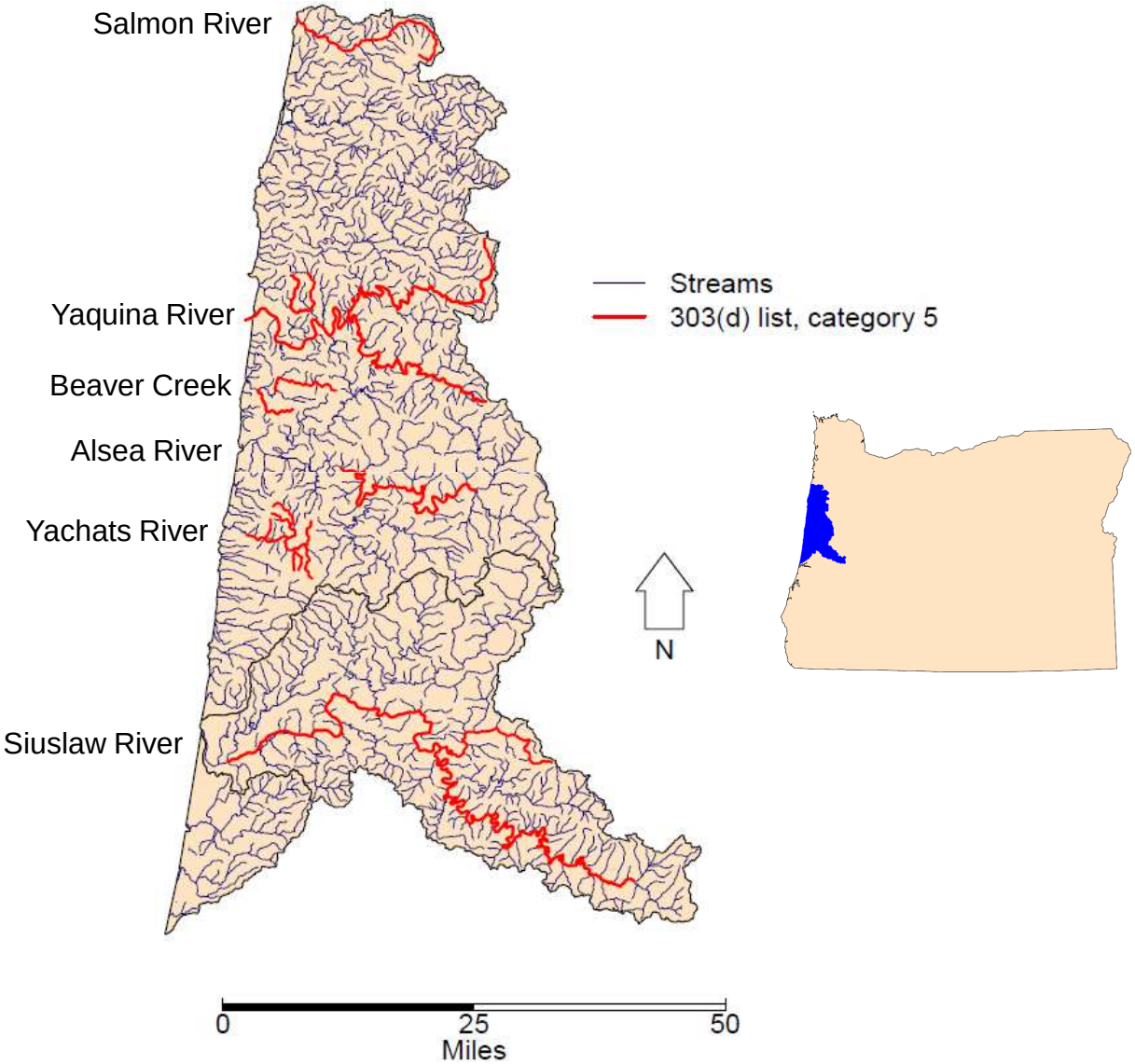

DO Listings in the Mid Coast (2010 Integrated Report)

River/stream	River miles	Listing Period	Criteria
Salmon River	0 – 23.1	Sep 15 – May 31	Spawning
Depot Creek	0 – 4.5	Year Around	Cold Water
Beaver Creek (Yaquina)	0 – 7.3	Oct 15 – May 15	Spawning
Beaver Creek (Yaquina)	0 – 7.3	Year Around	Cold Water
Yaquina River	0 – 26.9	Jan 1 – May 15	Spawning
Yaquina River	26.9 – 53.9	Oct 15 – May 15	Spawning
Yaquina River	0 – 56.8	Year Around	Cold Water
Big Elk Creek	0 – 5.3	Jan 1 – May 15	Spawning
Big Elk Creek	5.3 – 29.5	Oct 15 – May 15	Spawning
Big Elk Creek	0 – 29.5	Year Around	Cold Water
North Fork Beaver Creek	0 – 9.5	Oct 15 – May 15	Spawning
South Fork Beaver Creek	0 – 6	Oct 15 – May 15	Spawning
South Fork Beaver Creek	0 – 6	Year Around	Cold Water
Alsea River	15.7 – 27	Sep 15 – Jun 15	Spawning
Alsea River	27 – 47.4	Sep 1 – June 15	Spawning
Alsea River	15.7 – 47.4	Year Around	Cold Water
Williamson Creek	0 – 2.7	Oct 15 – May 15	Spawning
North Fork Yachats River	0 – 6.3	Oct 15 – May 15	Spawning
Beamer Creek	0 – 2.1	Oct 15 – May 15	Spawning
School Fork	0 – 3.2	Oct 15 – May 15	Spawning
Yachats River	3.4 – 16.6	Oct 15 – May 15	Spawning
Keller Creek	0 – 2.6	Oct 15 – May 15	Spawning
Stump Creek	0 – 2	Oct 15 – May 15	Spawning
Siuslaw River	5.7 – 105.9	Sep 15 – May 31	Spawning
Siuslaw River	5.7 – 105.9	Year Around	Cold Water
Wildcat Creek	0 – 18.8	Oct 15 – May 15	Spawning

http://www.deq.state.or.us/wq/assessment/2010Report.htm

Dissolved oxygen data from the Mid Coast

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- Since 2000, grab samples and continuous data collected

Dissolved oxygen data from the Mid Coast

- Since 2000, grab samples and continuous data collected
- In 2008, DEQ collected continuous DO in six river basins
  - Spring, Summer, and/or Fall
  - 15-minute intervals for 3-5 days (DO and temperature)
  - Grab sample data for nutrients, pH, and BOD
  - Intended to populate QUAL2Kw – a mechanistic model

Continuous DO data

Photo by York Johnson

Continuous DO data

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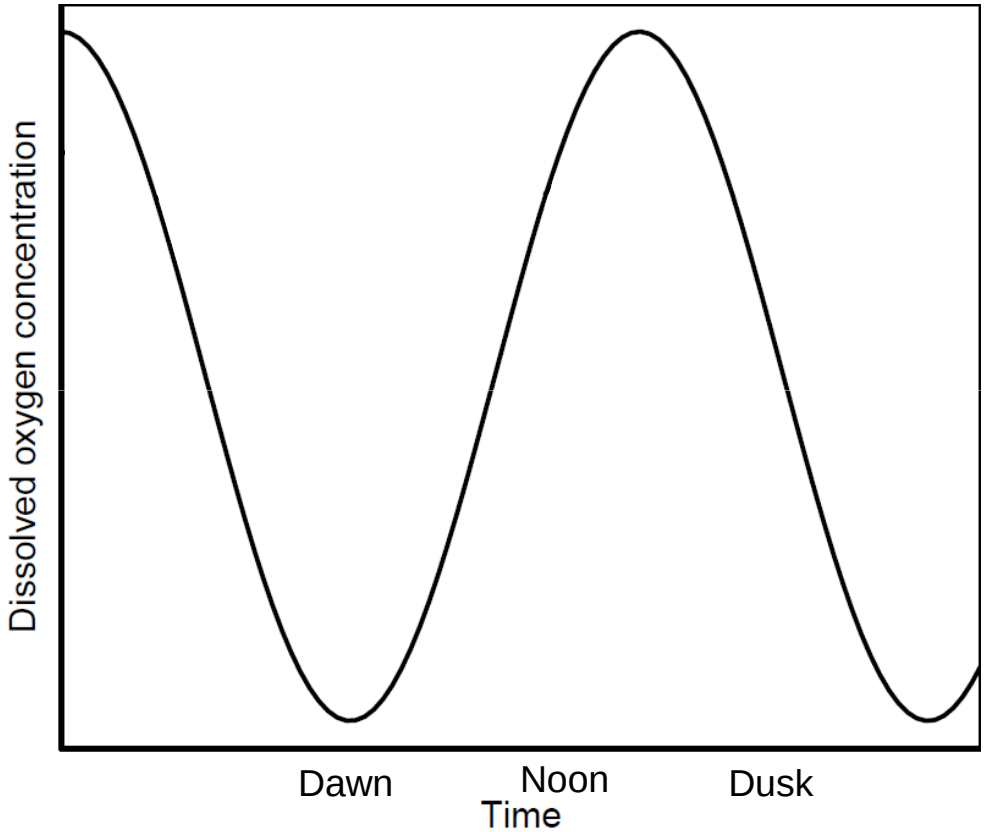
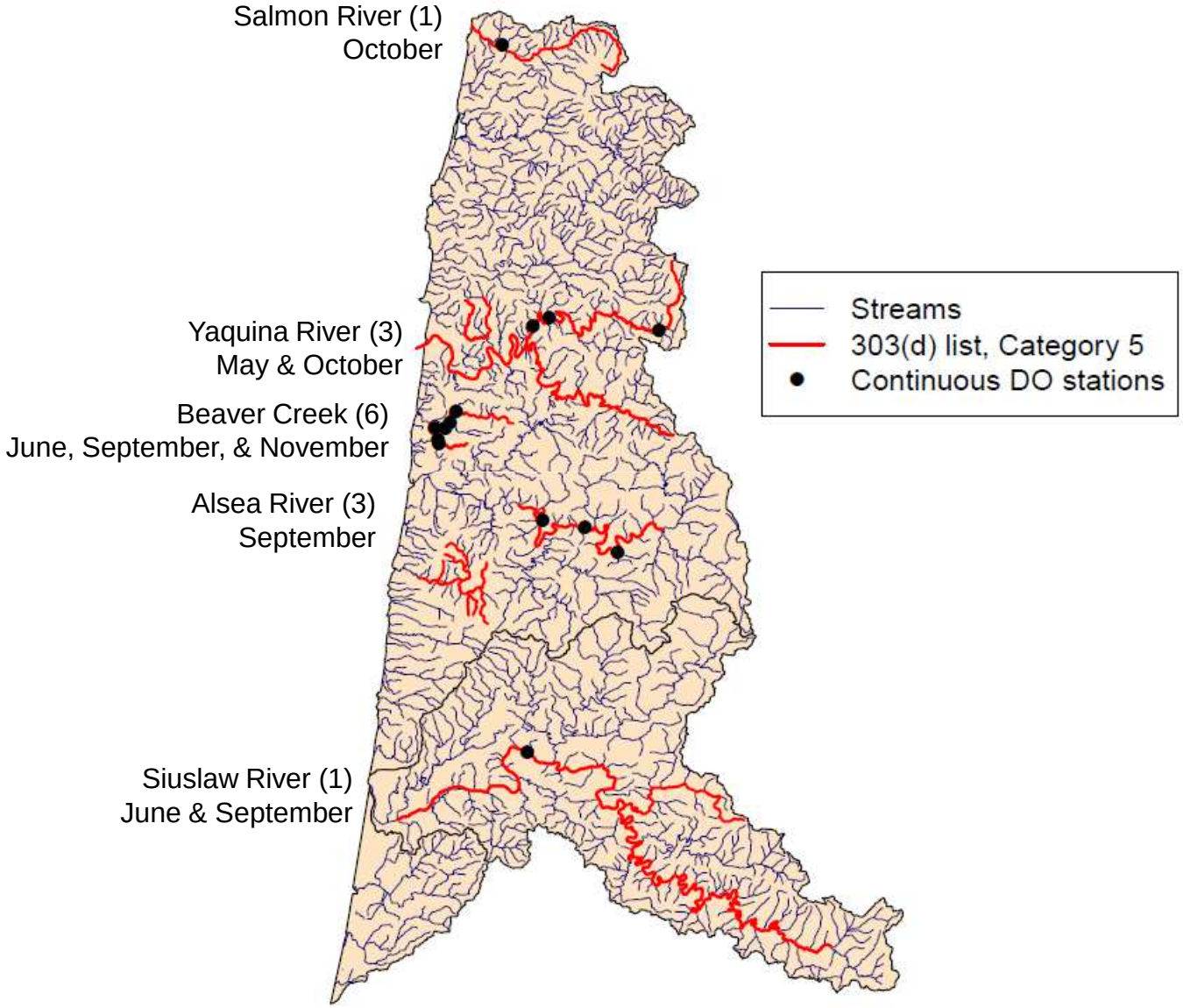
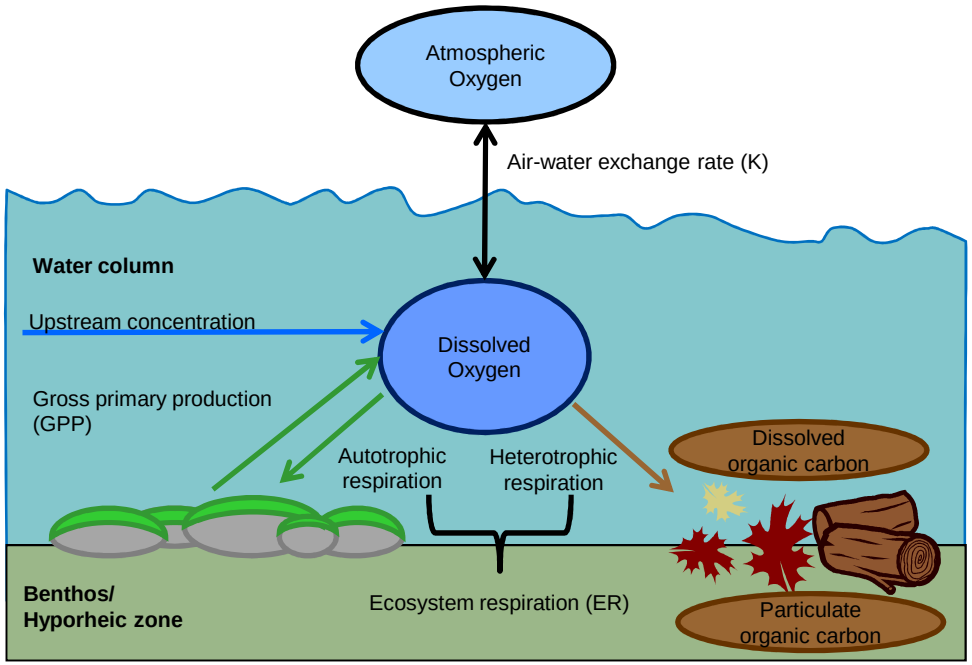


Continuous DO data from the Mid Coast - 2008

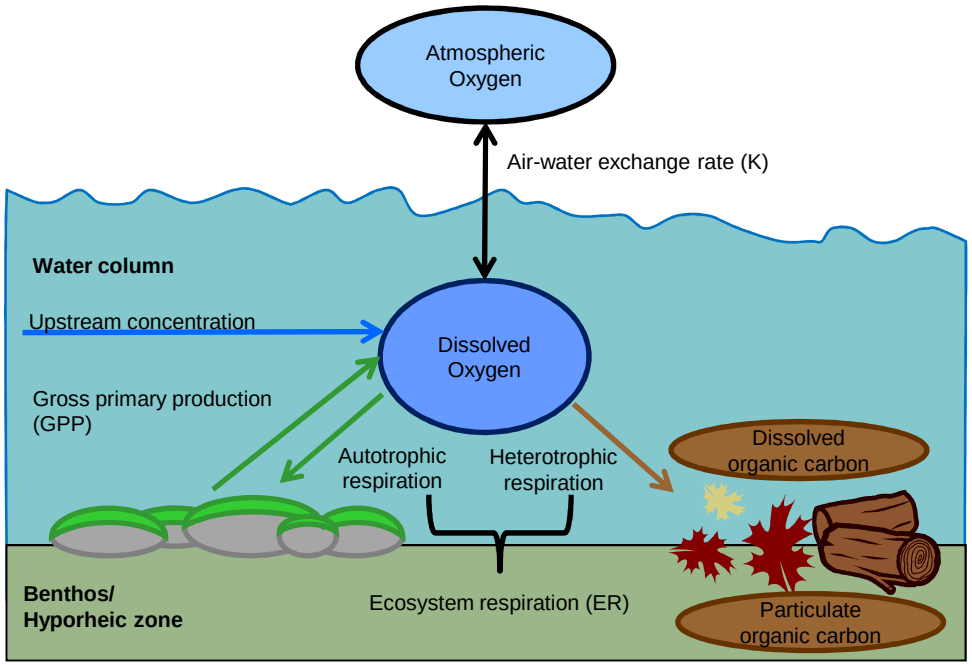


Mid Coast dissolved oxygen analysis objectives



Mid Coast dissolved oxygen analysis objectives

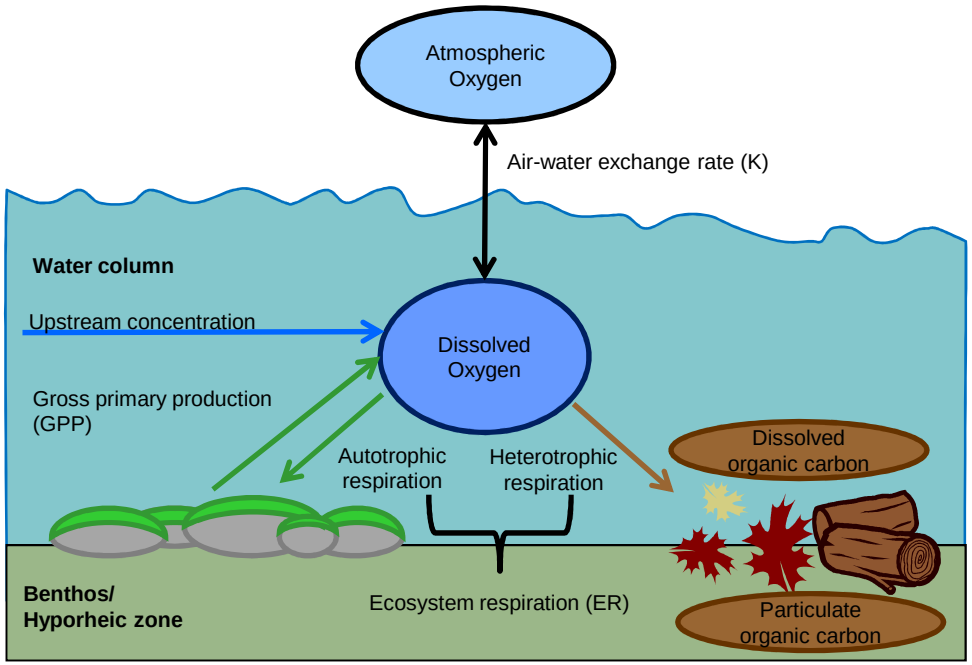
- Use continuous DO data to model air-water exchange, gross primary production, & ecosystem respiration



Mid Coast dissolved oxygen analysis objectives

- Use continuous DO data to model air-water exchange, gross primary production, & ecosystem respiration

- Determine which rivers can be used for mechanistic modeling of DO dynamics



What DO data are useable for this analysis?

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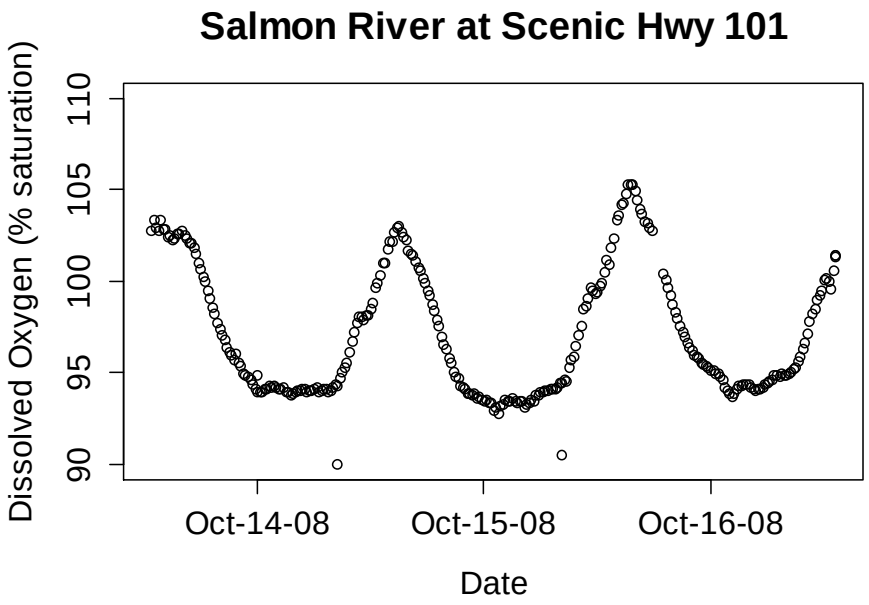
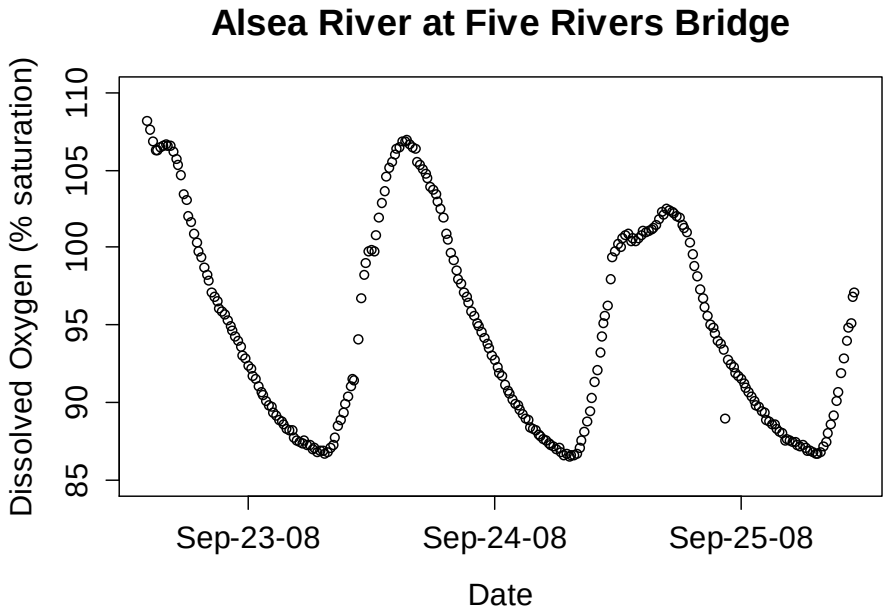
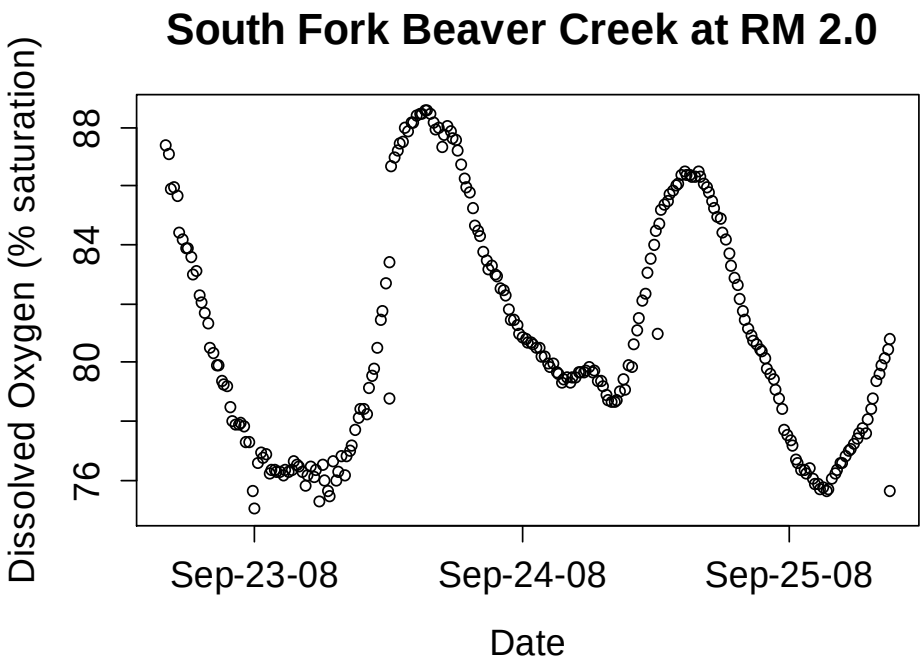
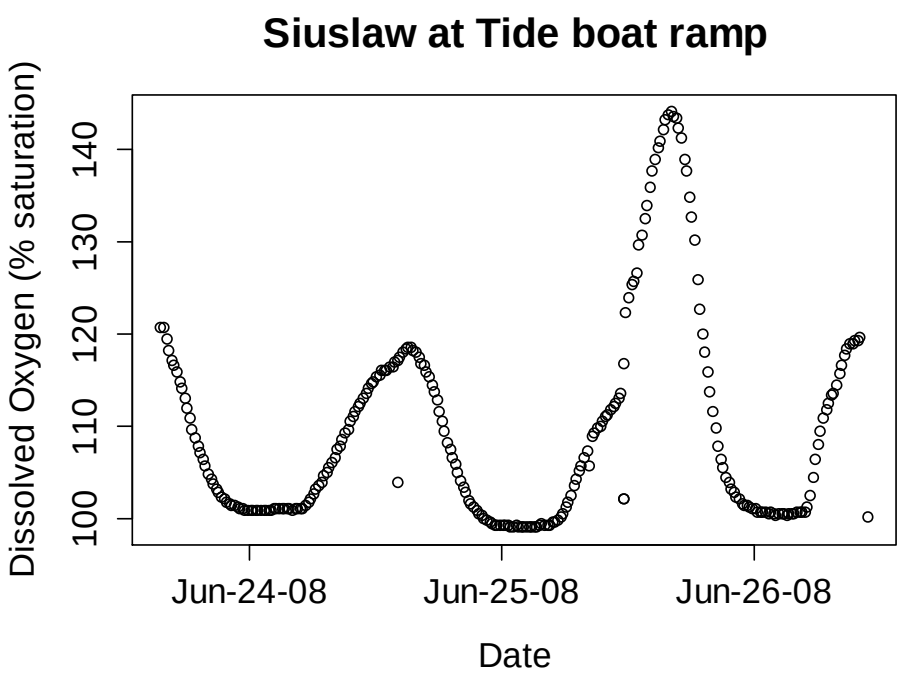




<u>At or near steady state</u>

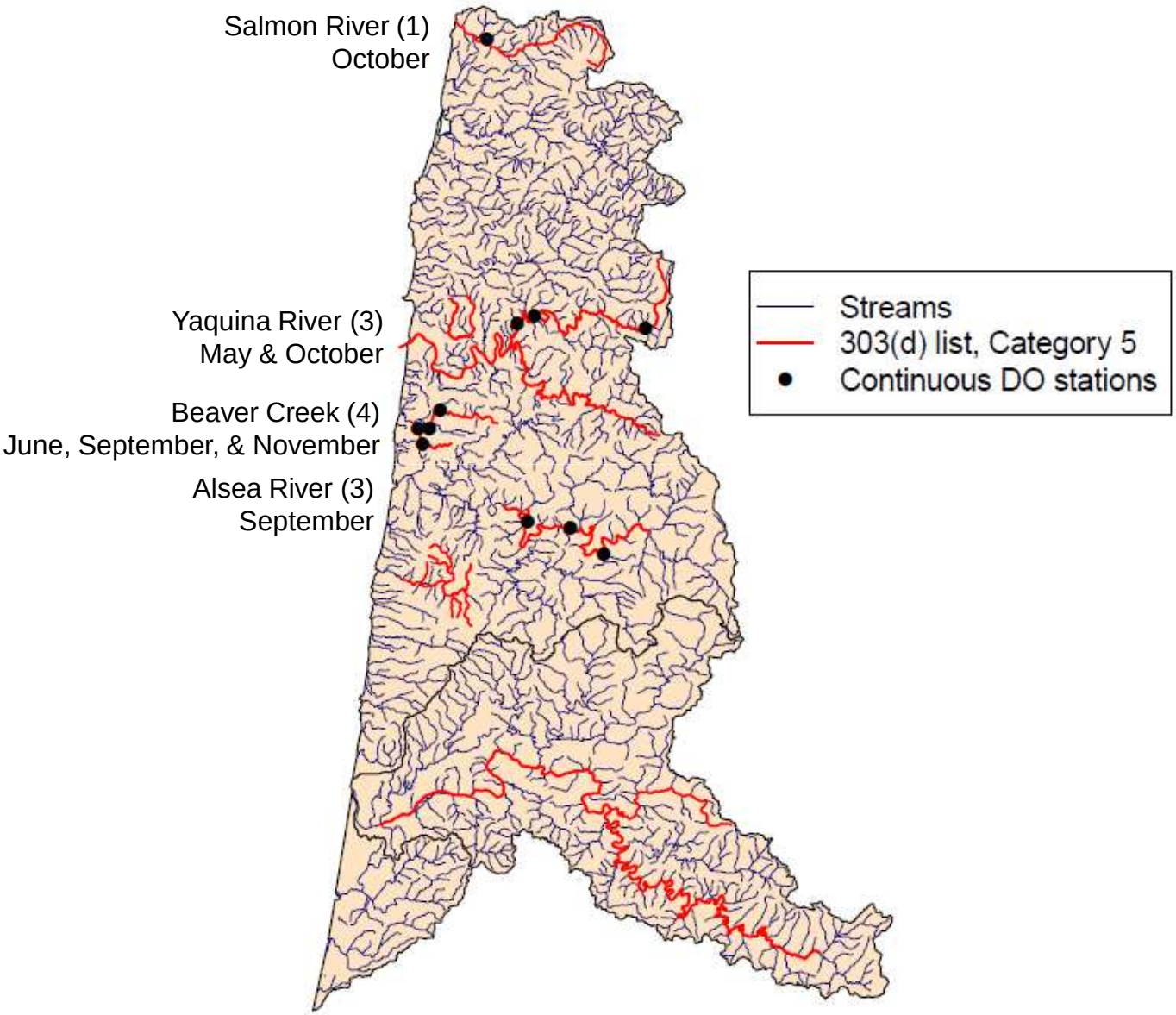
What DO data are not useable for this analysis?



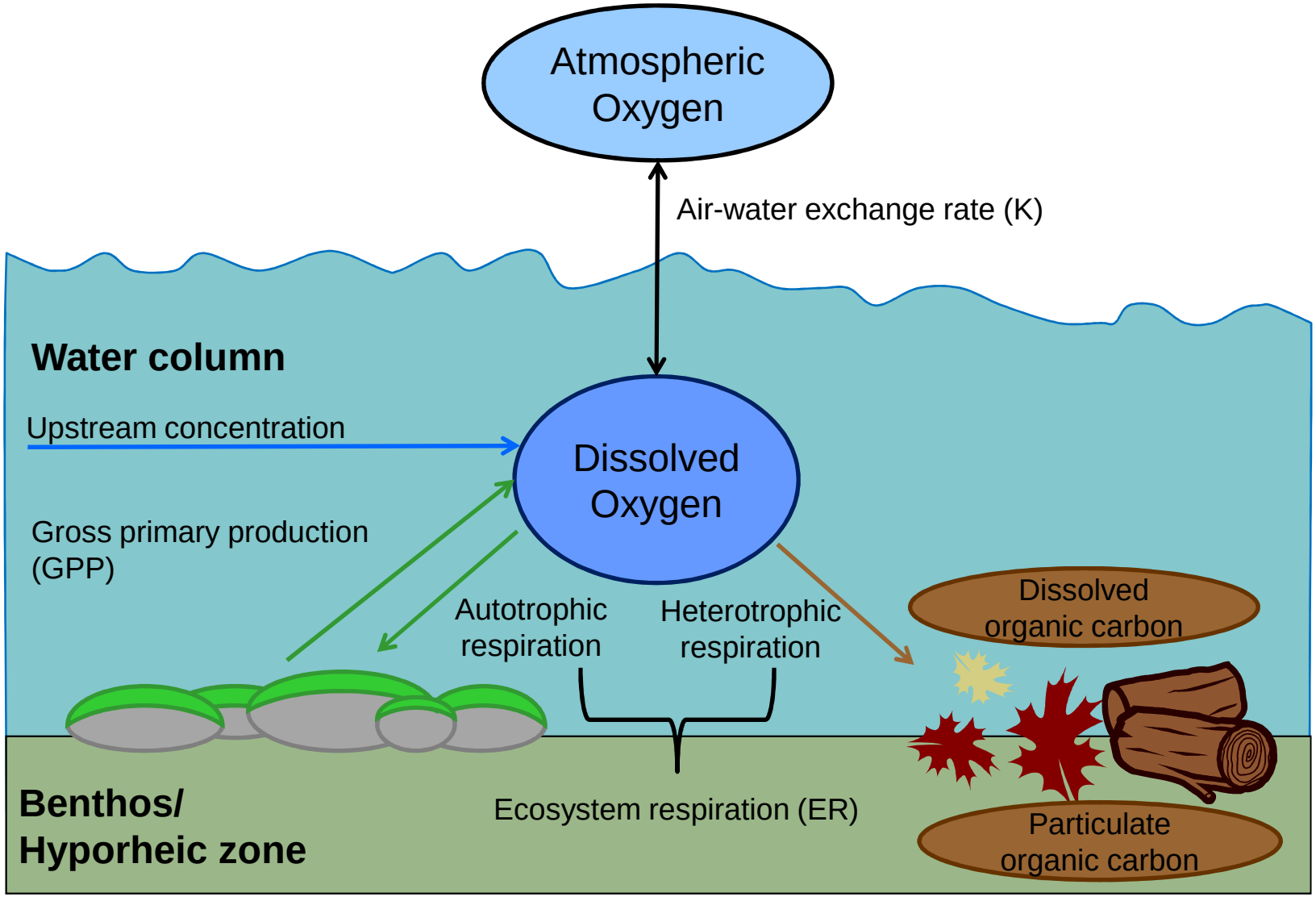


<u>Not at steady state</u>

Steady-state continuous DO data - 2008

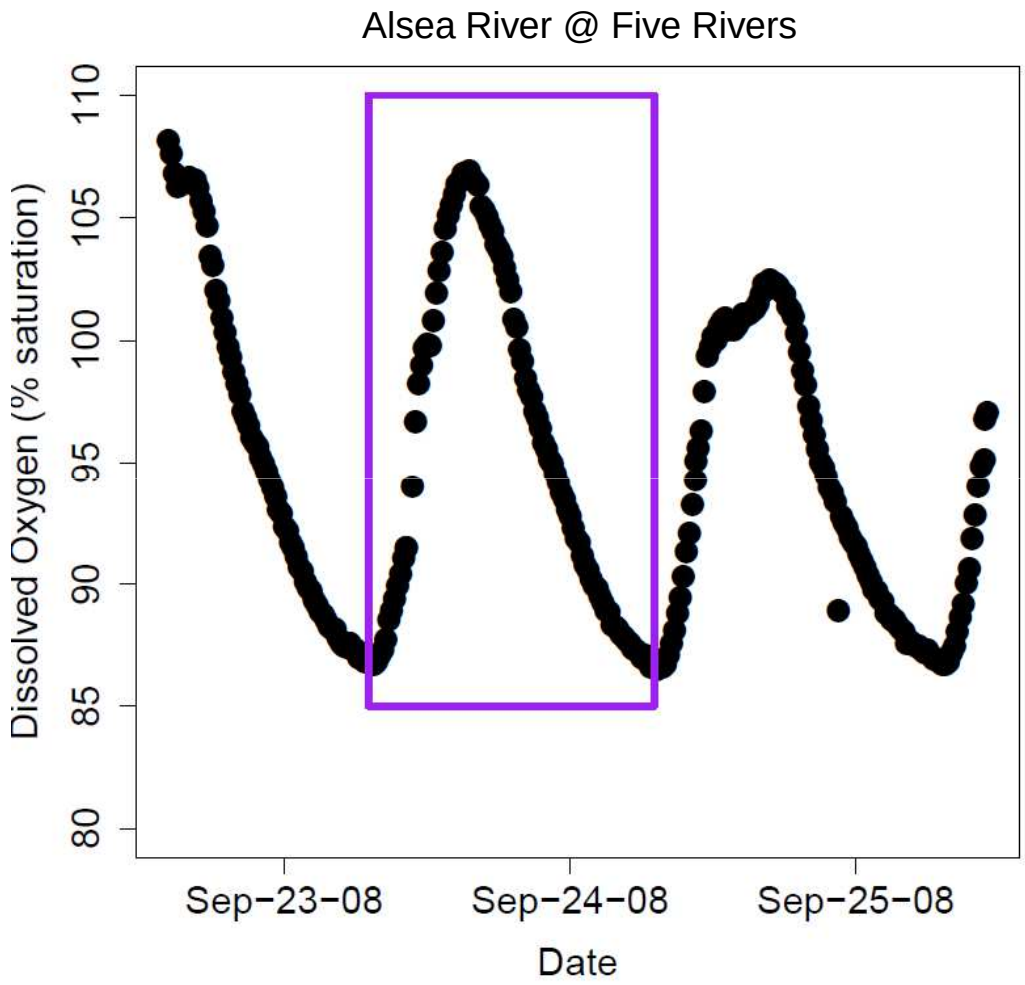


How did we model DO dynamics from continuous data?



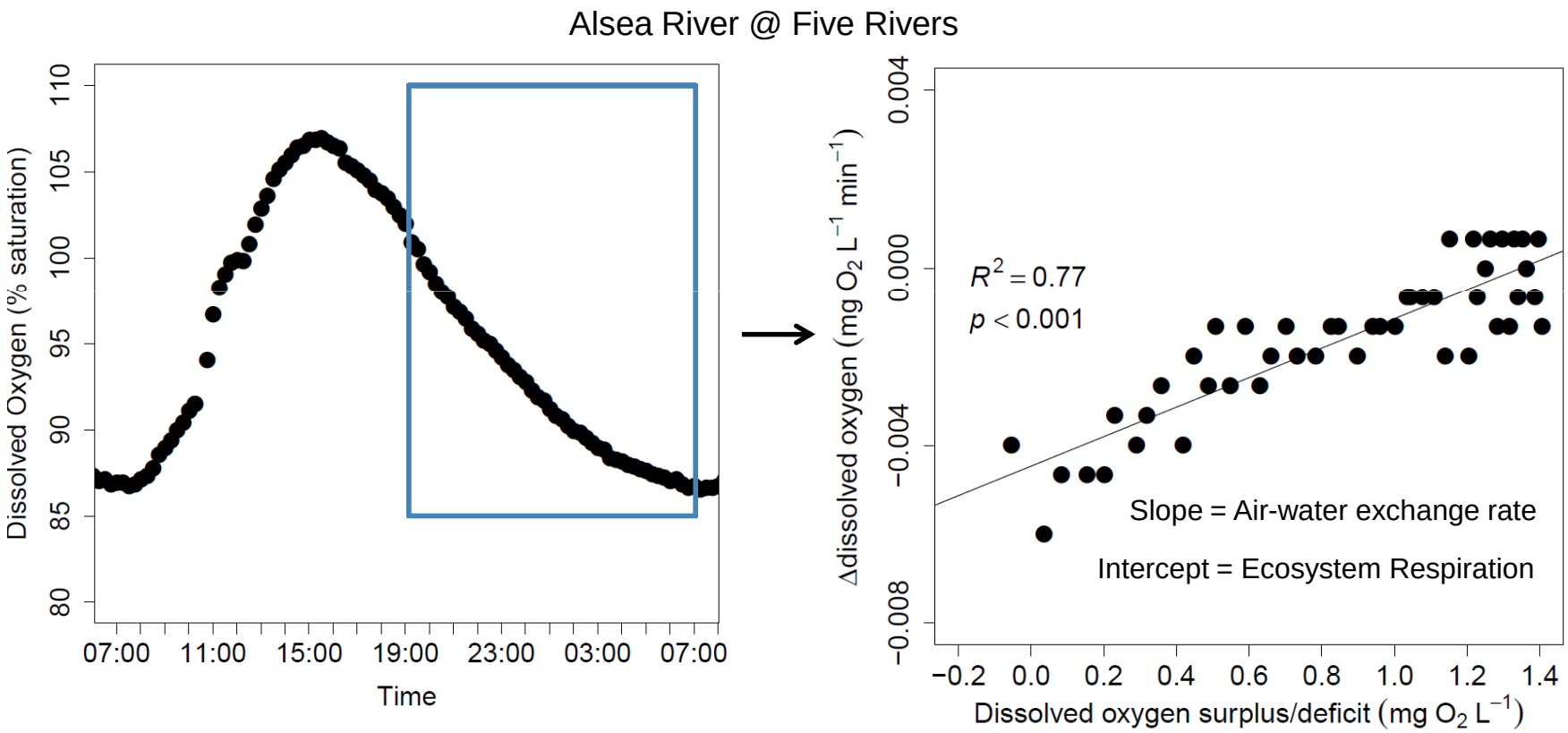
How did we model DO dynamics from continuous data?

- Selected a 24-hr cycle within each period



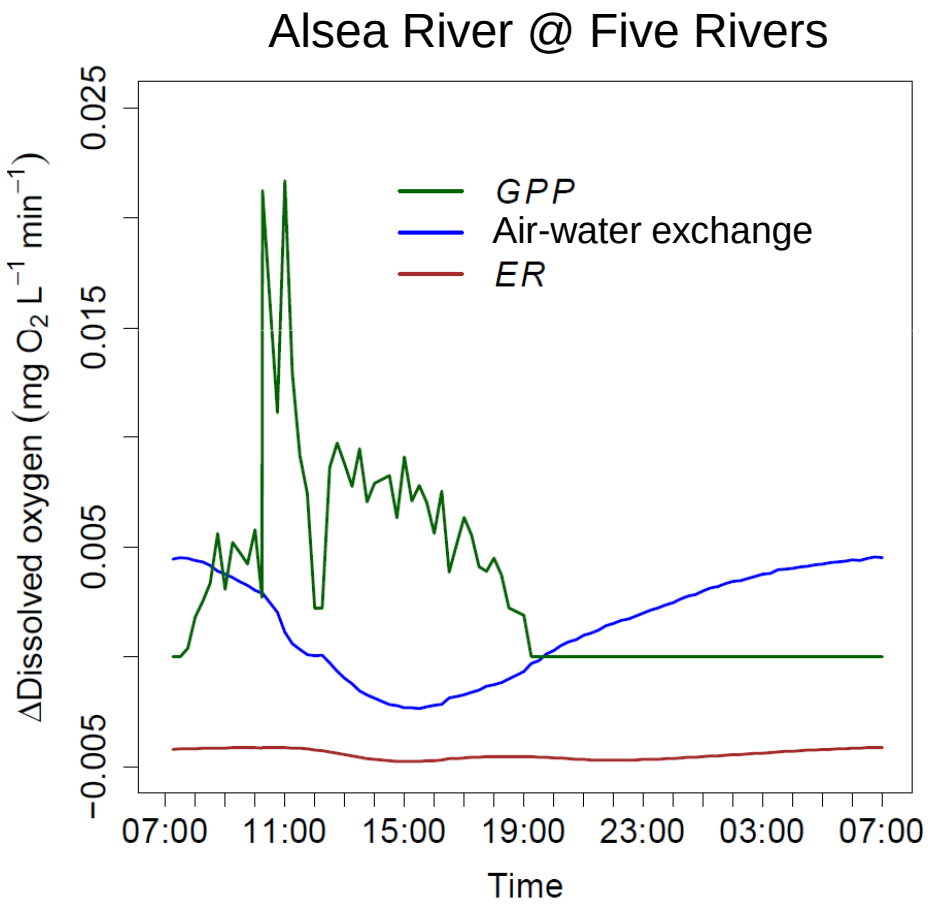
How did we model DO dynamics from continuous data?

- Night-time regression method for air-water exchange & ER



How did we model DO dynamics from continuous data?

- Solved for primary production during daylight



Preliminary results

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- Estimates of K, ER, and GPP comparable to other rivers

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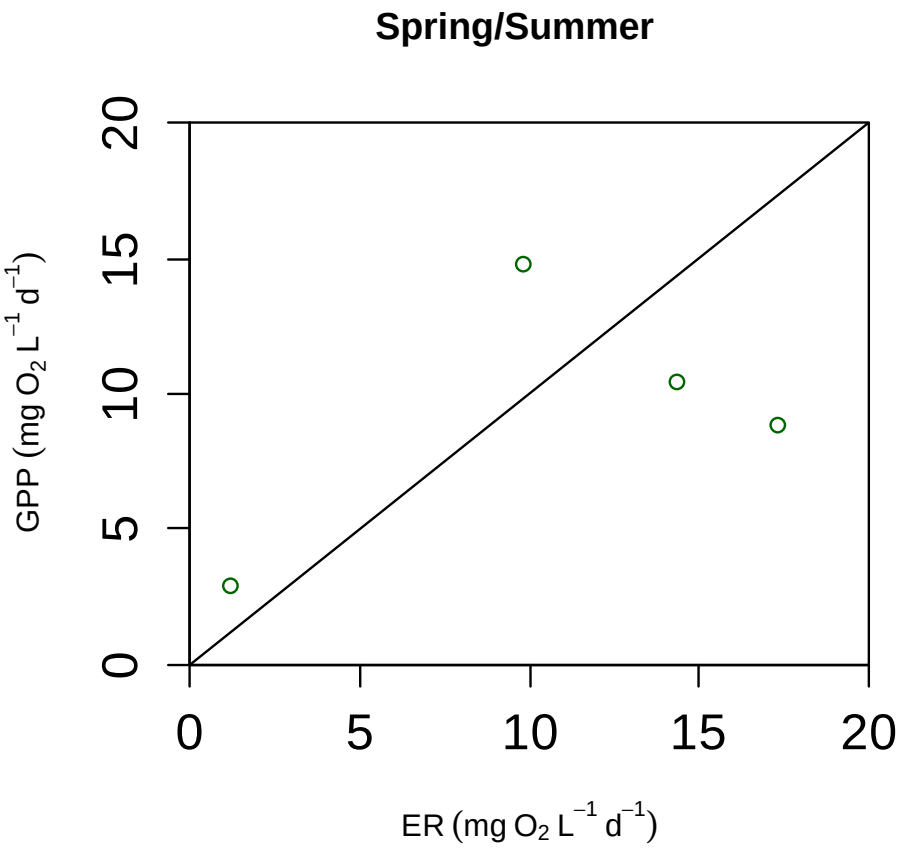
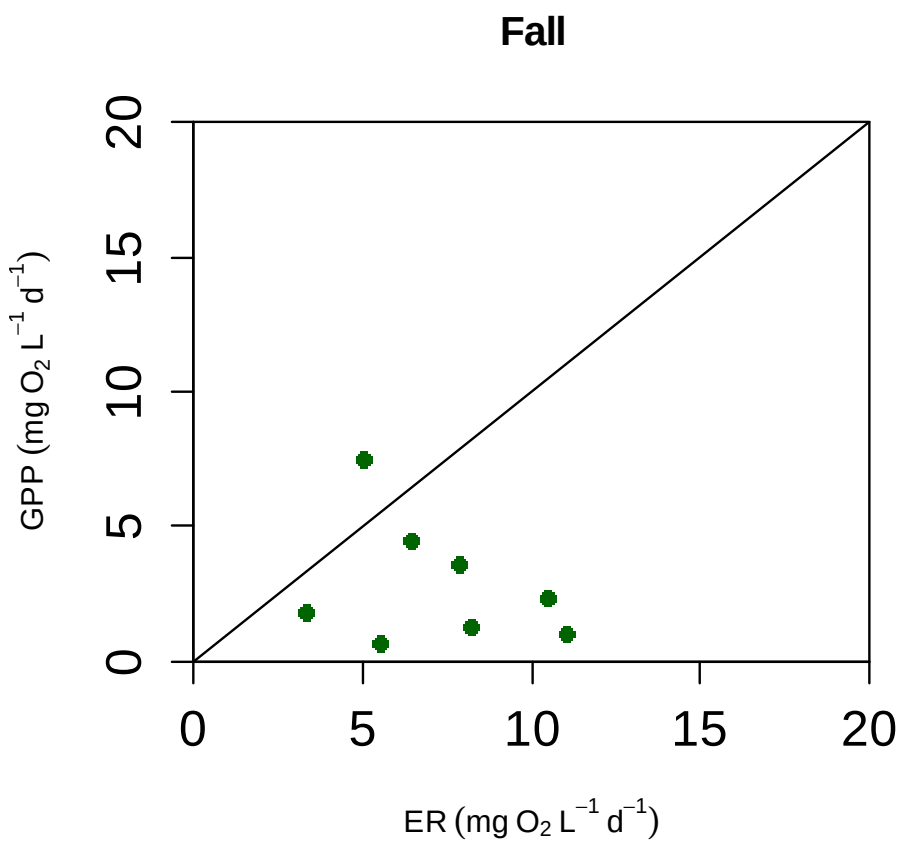
- Estimates of K, ER, and GPP comparable to other rivers

- In the Fall, ER consumed more DO than GPP produced
  - Points toward decomposition of organic matter as important

- In the Spring/Summer, pattern was less clear
  - Mix of light, nutrient, and temperature limitations?

GPP vs. ER


Spring/Summer
GPP (mg O2 L−1 d−1)
ER (mg O2 L−1 d−1)
0
5
10
15
20


Fall
GPP (mg O2 L−1 d−1)
ER (mg O2 L−1 d−1)
0
5
10
15
20

Other important findings

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- Temperature important for estimating K, GPP, and ER

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- River flow might influence ER

Other important findings

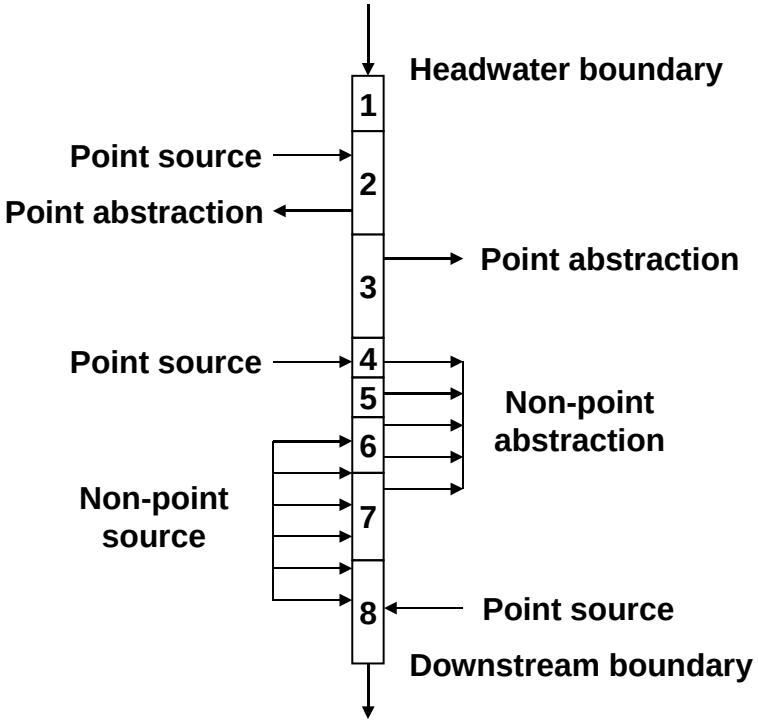
- Temperature important for estimating K, GPP, and ER
- River flow might influence ER
- GPP & ER in these rivers might be phosphorus limited

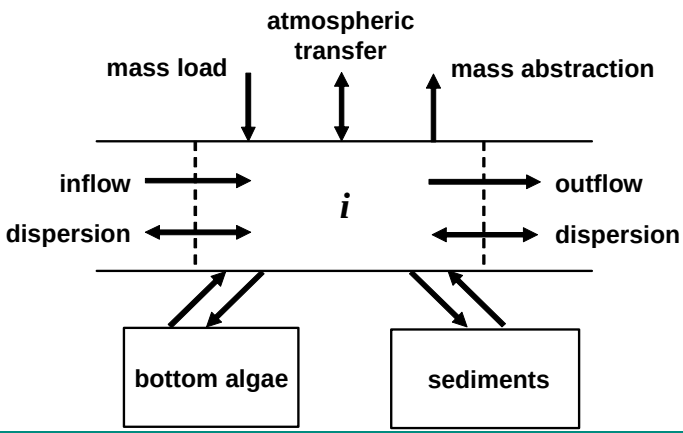
Next steps

Next steps

- Basin-specific, mechanistic model – QUAL2Kw (proposed)
  - Proposed pilot basins: Alsea & Yaquina

Proposed model: QUAL2Kw





- Mechanistic, mass balance model
- Uses estimates of K, GPP, & ER
- EPA-approved model (http://www.ecy.wa.gov/programs/eap/models.html)
- Used for TMDLs in Oregon & Washington

Next Steps

- Basin-specific, mechanistic model – QUAL2Kw (proposed)
  - Proposed pilot basins: Alsea & Yaquina

- Work with local technical workgroup (temperature TWG)
  - Initial meeting: October 2015
  - Set additional schedule afterwards
  - Discuss modeling options for non steady-state data
  - New data?

Acknowledgments

Kevin Brannan, ODEQ

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Julia Crown, ODEQ

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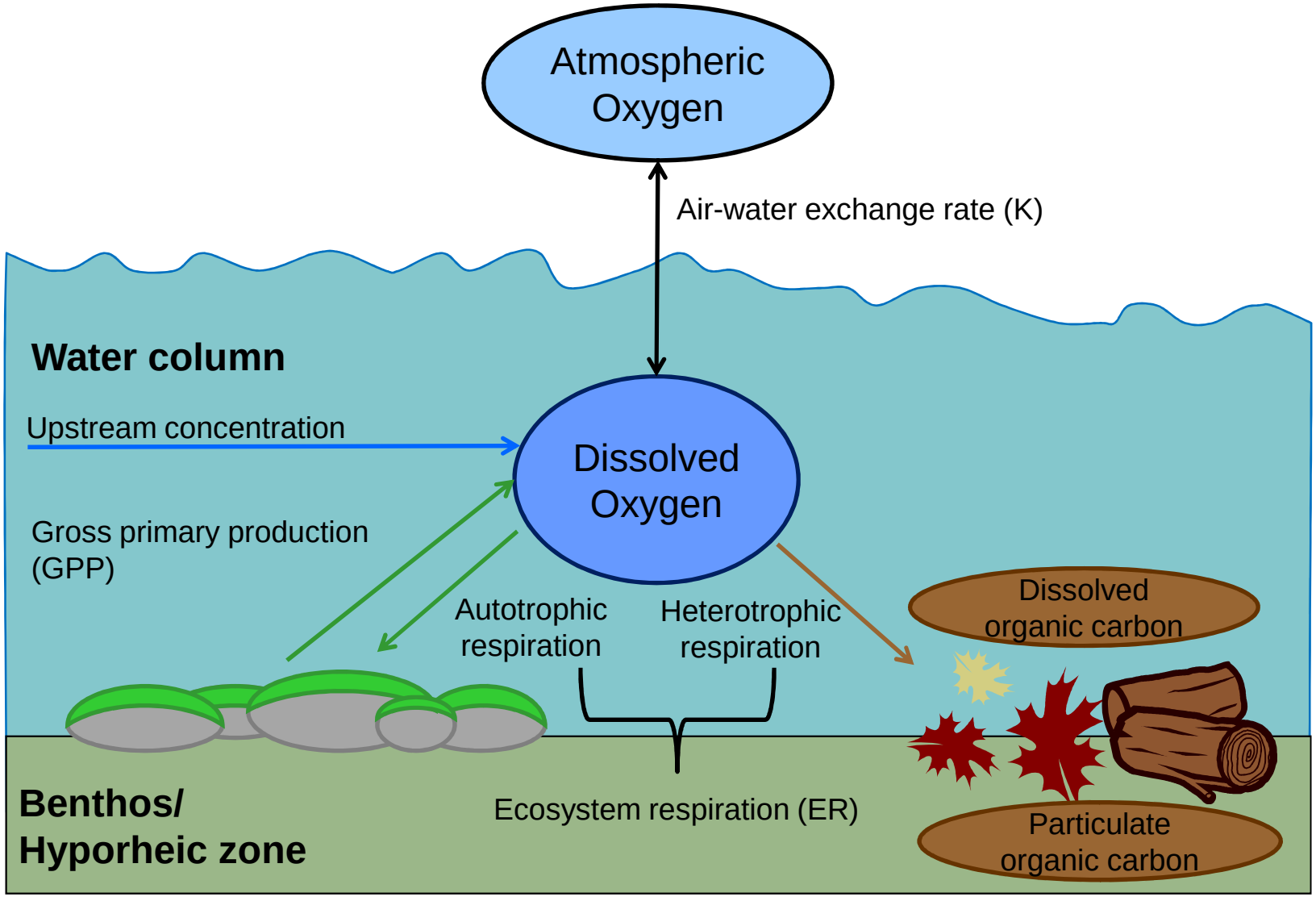
Bob Hall, University of Wyoming

Ryan Hill, US EPA

Keith Sawicz, US EPA

Questions?


Atmospheric Oxygen
Air-water exchange rate (K)
Water column
Upstream concentration
Dissolved Oxygen
Gross primary production (GPP)
Autotrophic respiration
Heterotrophic respiration
Dissolved organic carbon
Ecosystem respiration (ER)
Particulate organic carbon
Benthos/ Hyporheic zone

Extra Slides

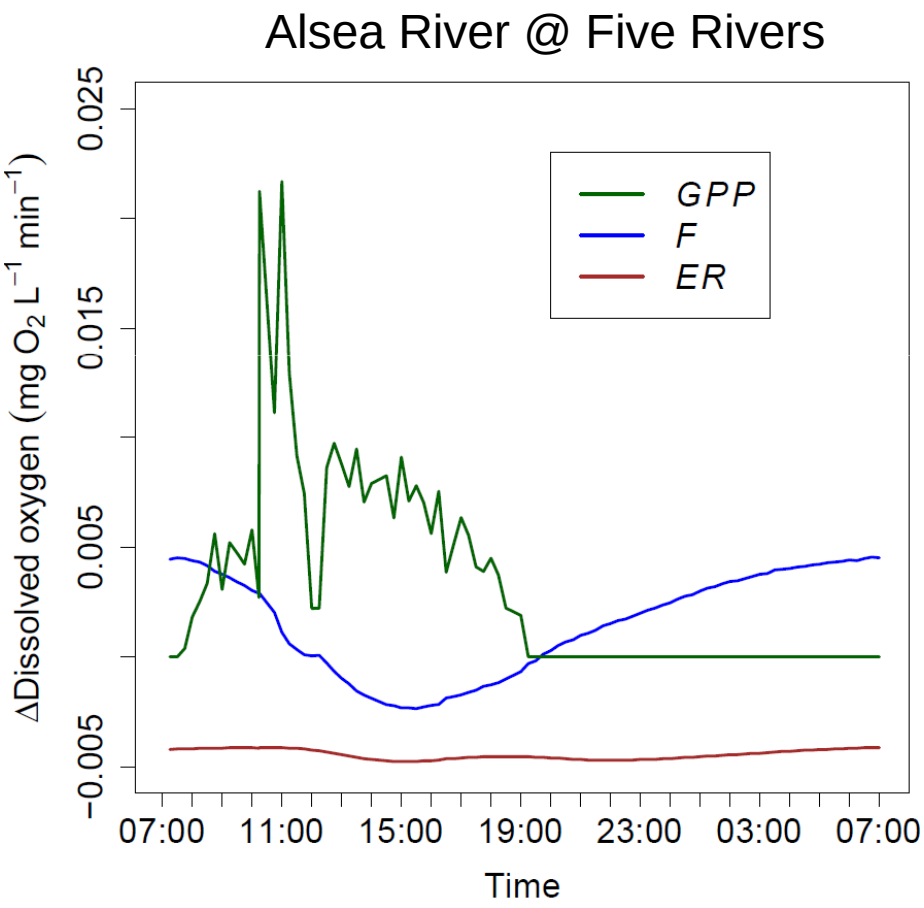
Scaling estimates across 24-hr cycle

$$K_t = K_N * 1.024^{T_t - T_N}$$

$$ER_t = ER_N * 1.07^{T_t - T_N}$$

$$F_t = K_t * [DO_{t_def/sur}]$$

$$GPP_t = [DO_t] - F_t + ER_t$$



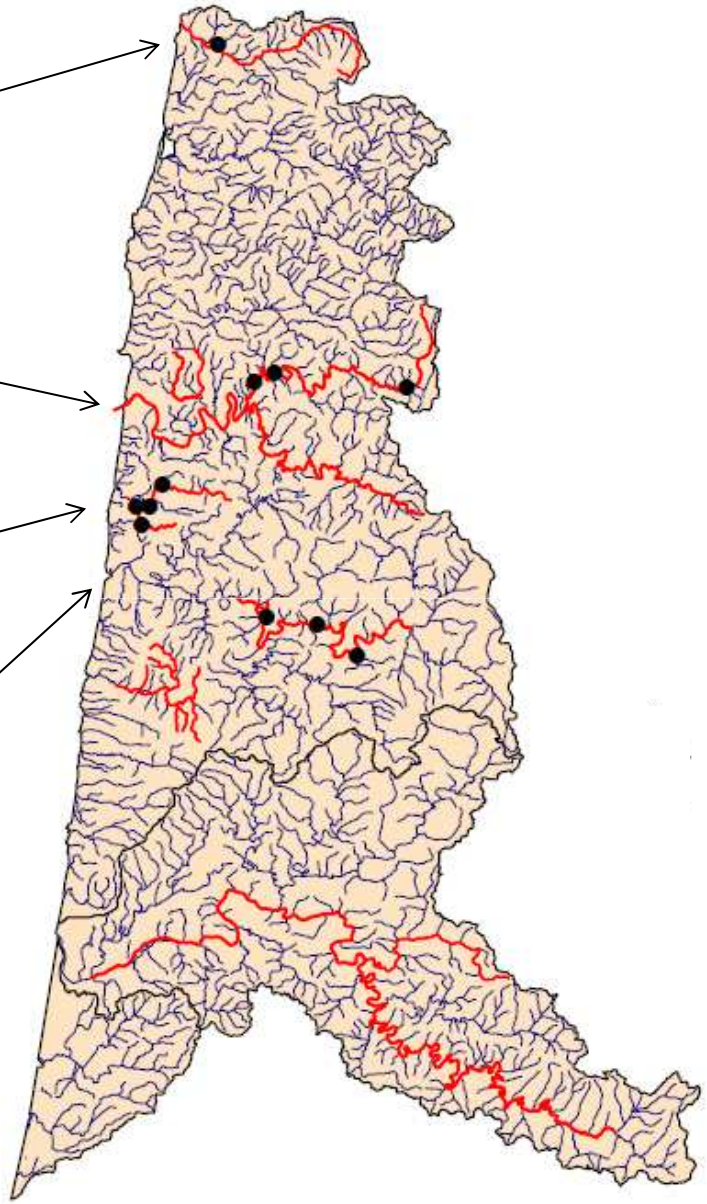
GPP – ER, Fall

Salmon River
-4.20 mg O_2/L/d

Yaquina River
-8.10 mg O_2/L/d
-6.90 mg O_2/L/d

Beaver Creek
-4.90 mg O_2/L/d
-10.00 mg O_2/L/d

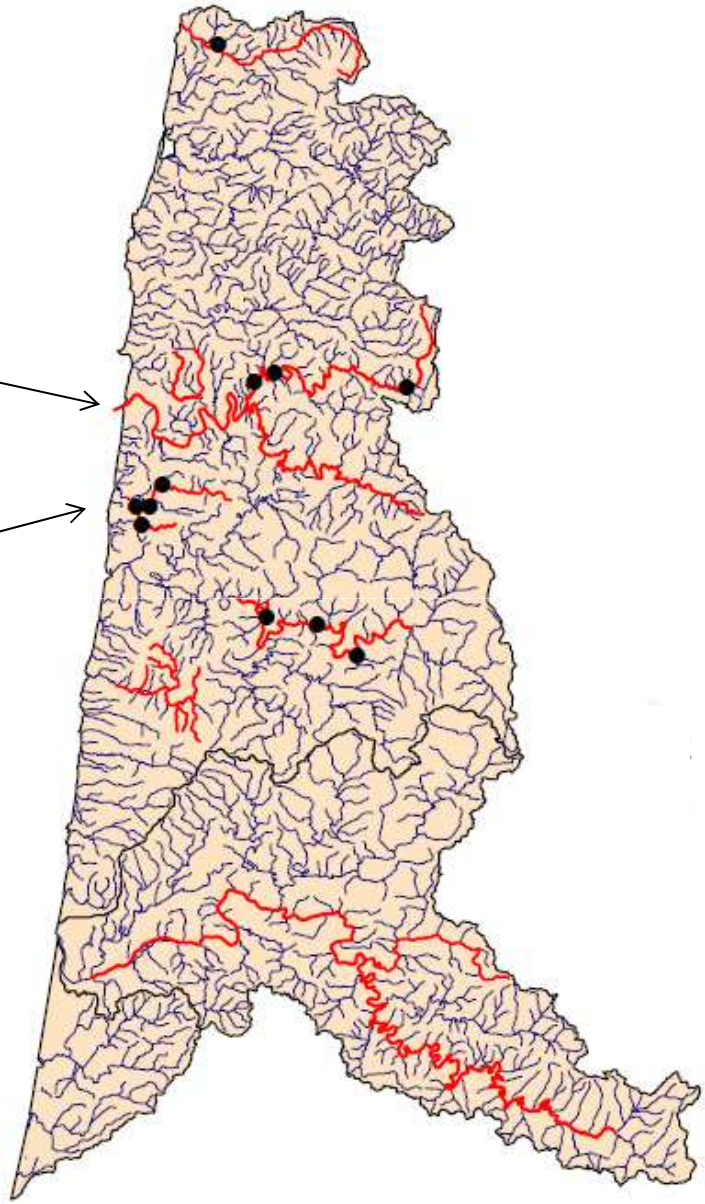
Alsea River
2.50 mg O_2/L/d
-1.90mg O_2/L/d
-1.50mg O_2/L/d



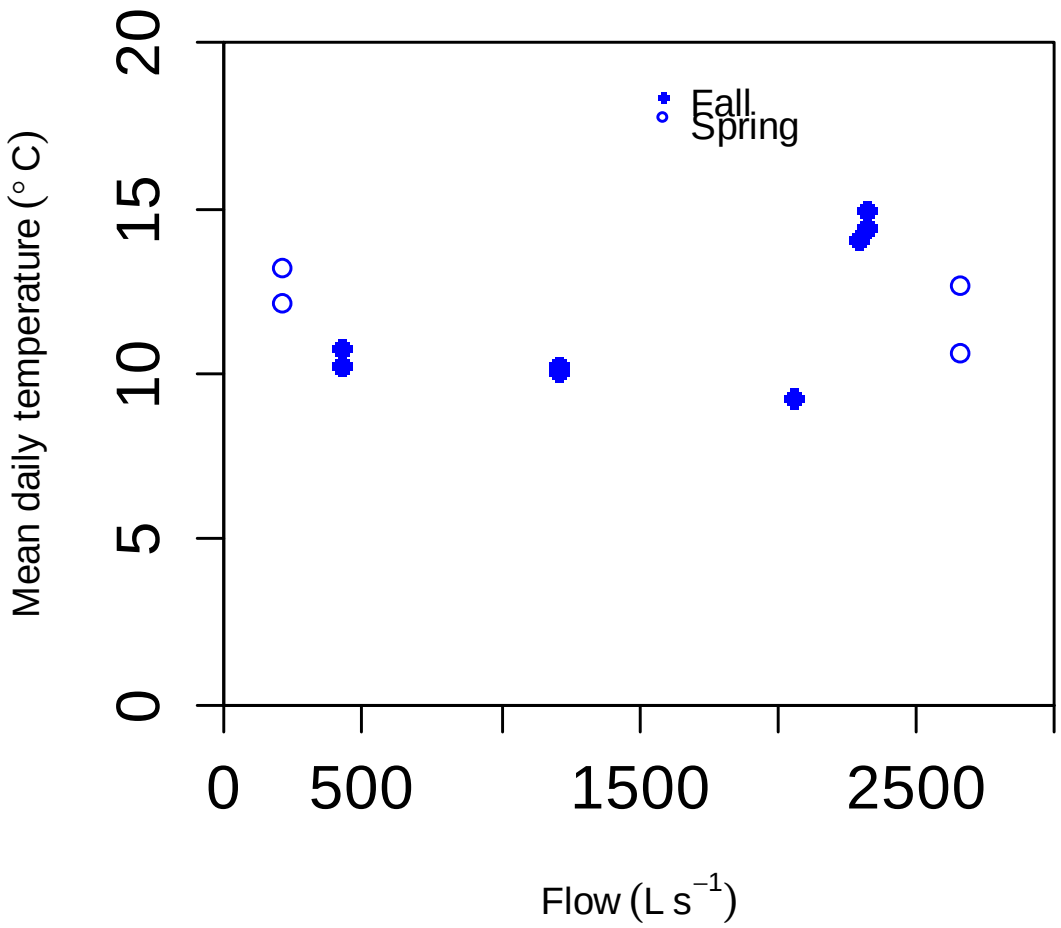
GPP – ER, Spring-Summer

Yaquina River
-3.90 mg O_2/L/d
1.70 mg O_2/L/d

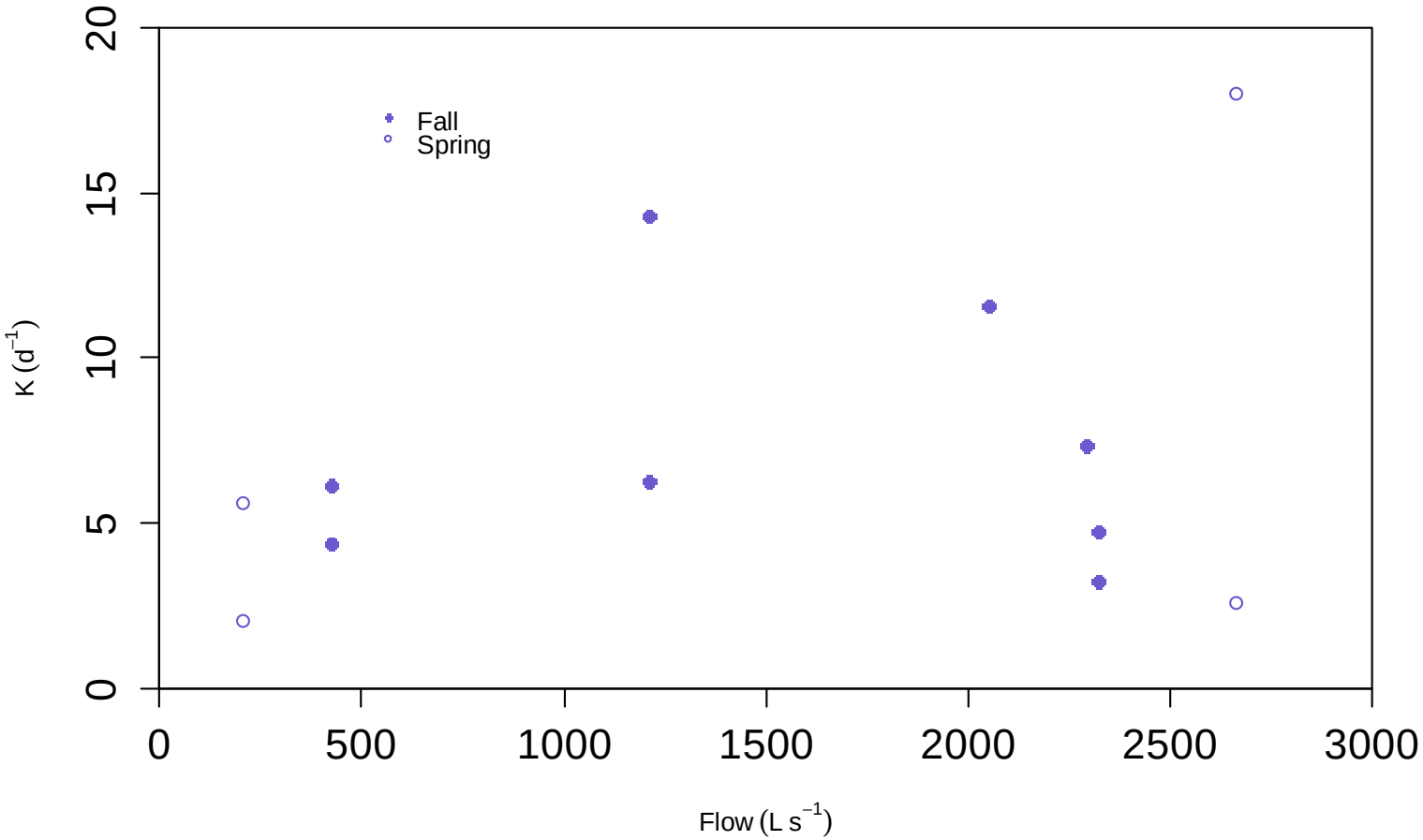
Beaver Creek
-8.50 mg O_2/L/d
4.90 mg O_2/L/d



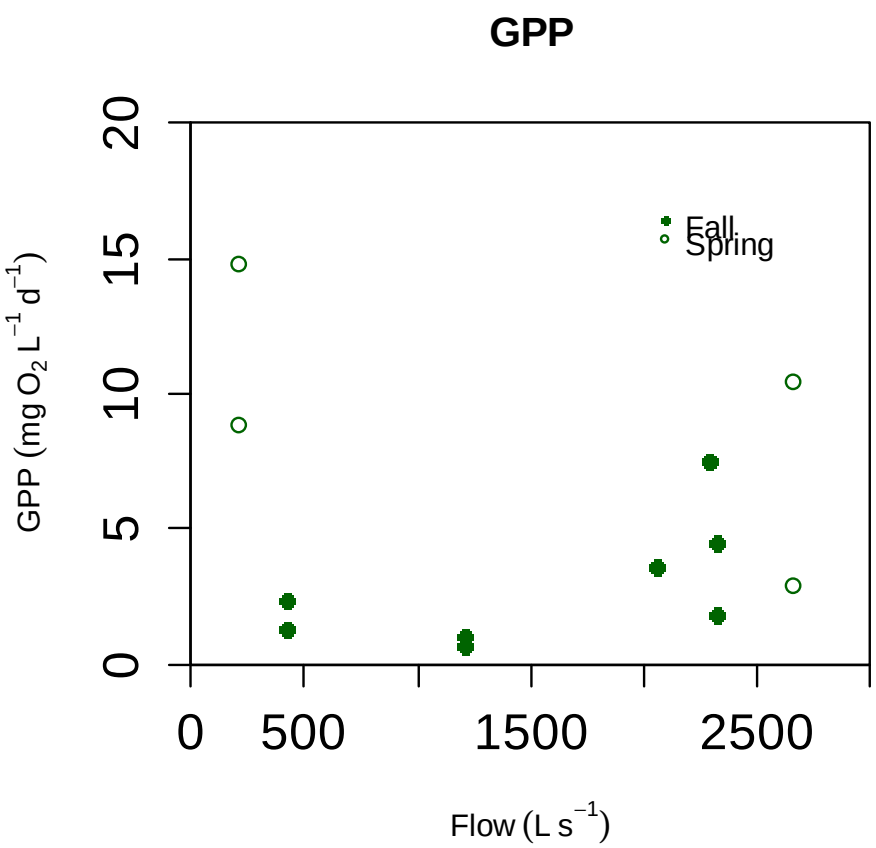
Temperature vs. Flow

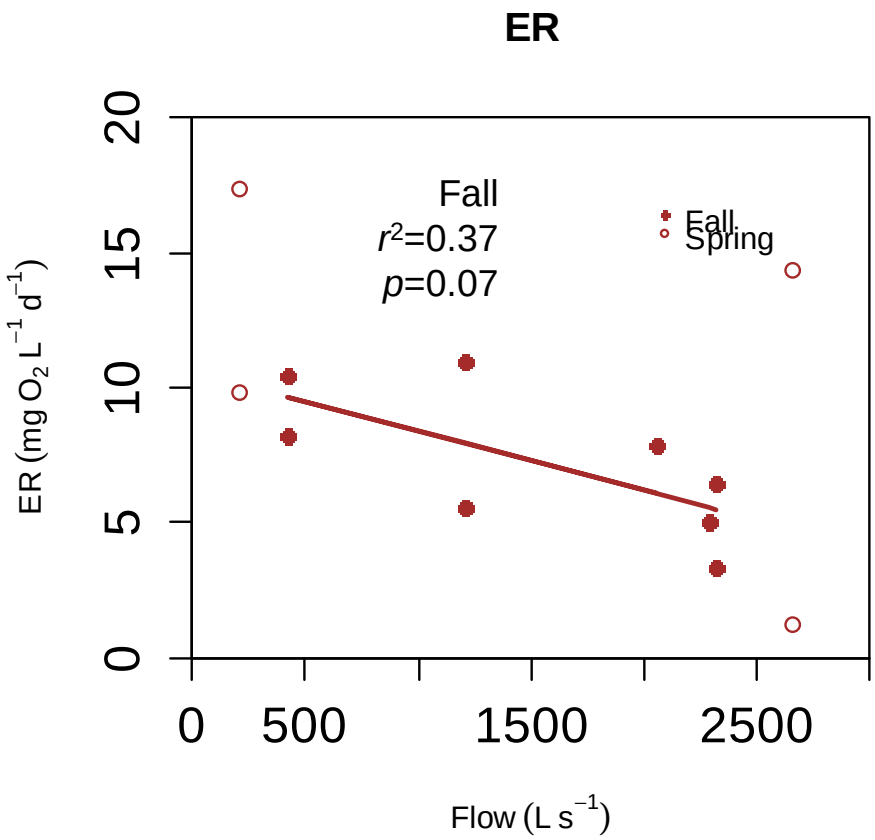


Reaeration vs. Flow

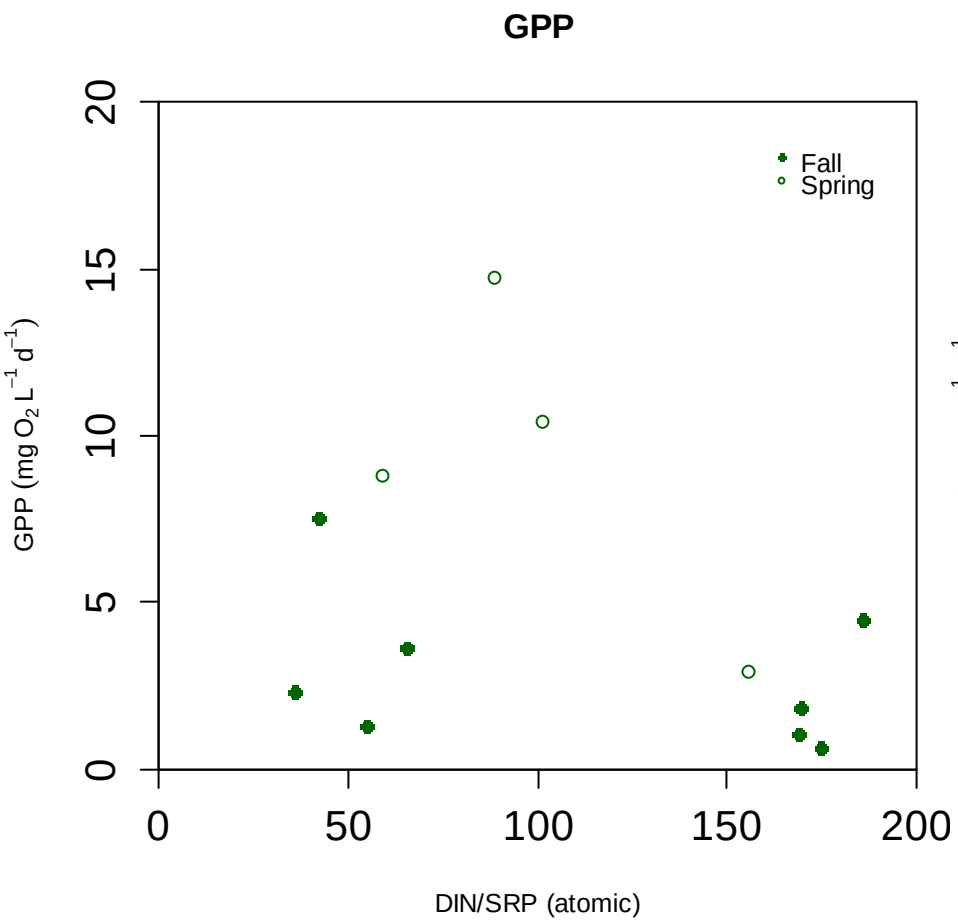


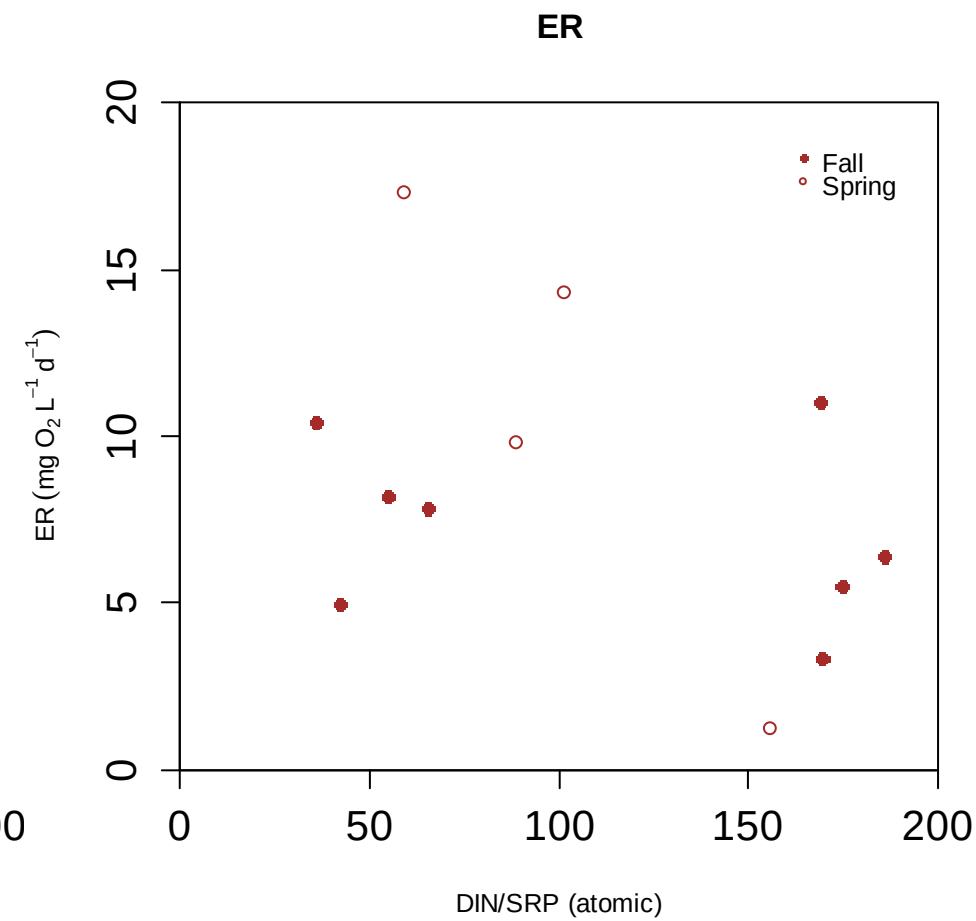
Metabolism vs. Flow



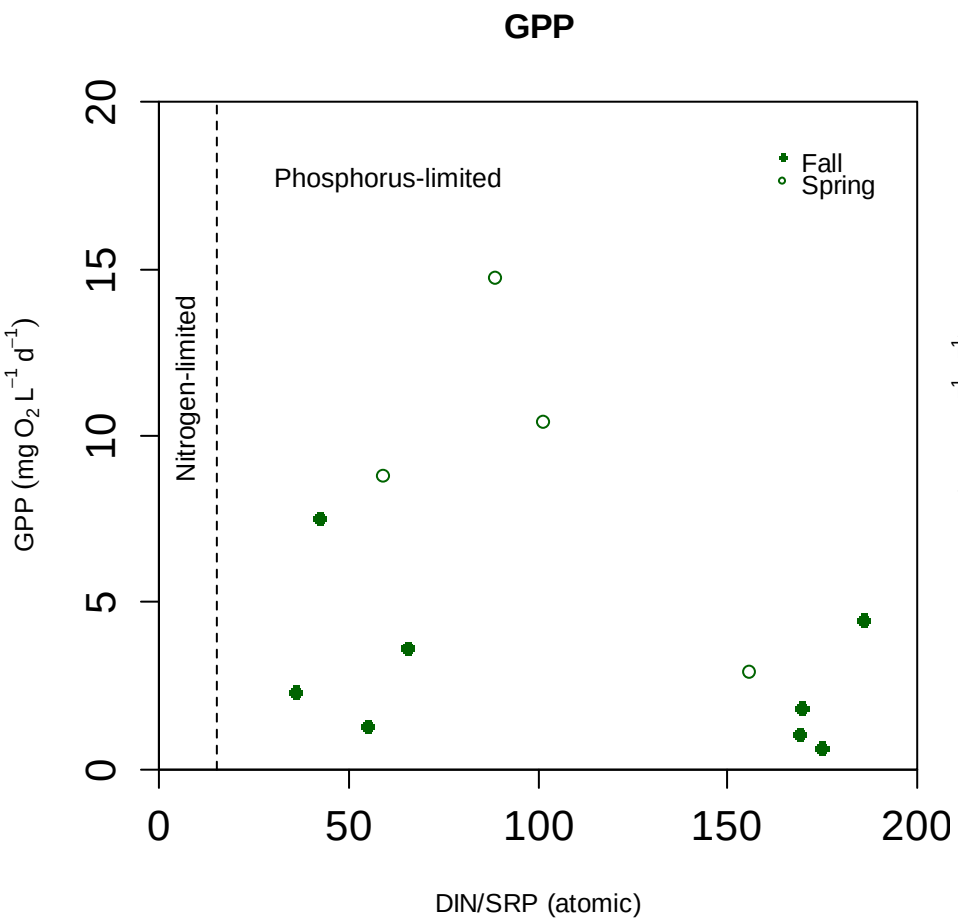


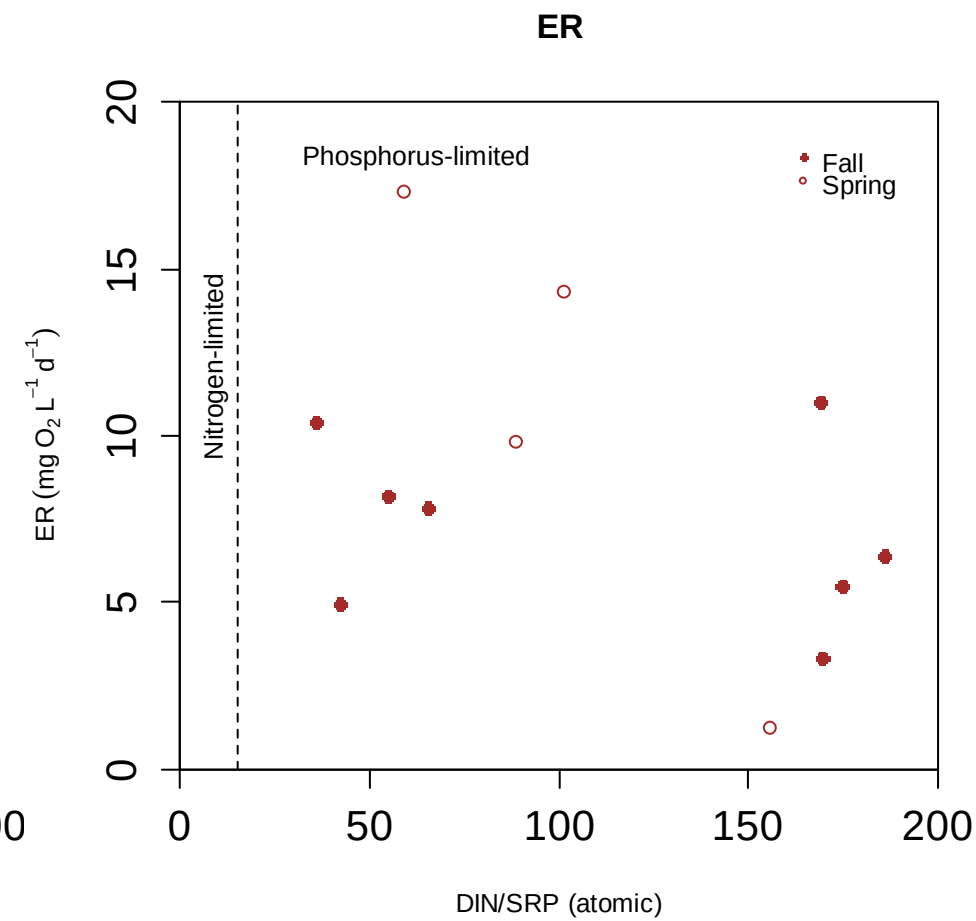
Metabolism vs. Nutrients





Metabolism vs. Nutrients





Conceptual model for dissolved oxygen analysis in Mid Coast rivers

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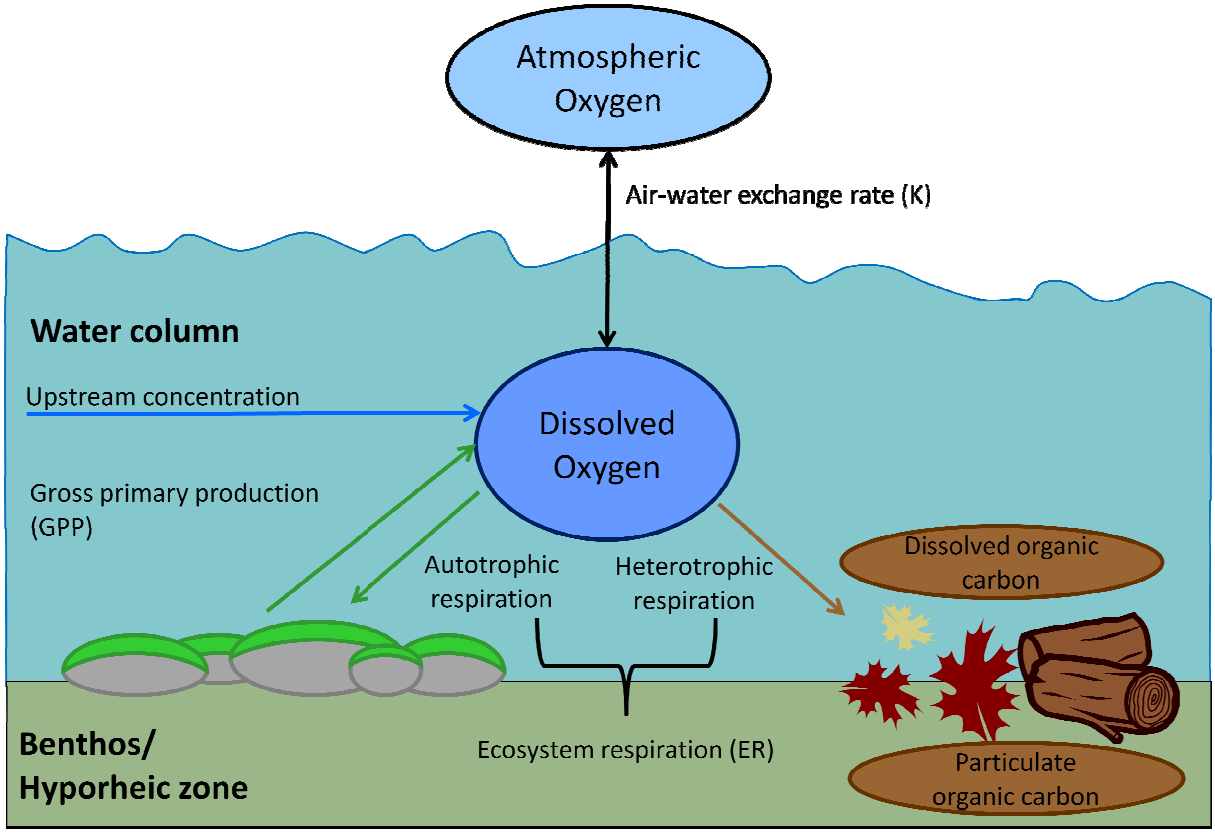

This conceptual model illustrates primary processes influencing dissolved oxygen concentrations in a stream or river reach. Dissolved oxygen concentration in upstream reaches sets the baseline for local processes (air-water exchange, gross primary production, and ecosystem respiration) to influence dissolved oxygen concentrations in a downstream reach. A glossary of terms in this figure can be found on the reverse side of this handout.

Glossary

Air-water exchange rate (K): The physical exchange of oxygen between the gaseous phase (atmosphere) and dissolved phase (water). K increases nonlinearly with warmer air and/or water temperatures and channel roughness/complexity.

Atmospheric oxygen: Oxygen in the gaseous phase (O_2). Atmospheric oxygen makes up approximately 21% of the air we breathe.

Autotrophic respiration: Respiration (oxygen consumption) by autotrophs (plants). Autotrophic respiration increases with gross primary production. Gross primary production minus autotrophic respiration is net primary production.

Benthos: The stream bottom.

Dissolved organic carbon: organic matter that can pass through a 0.7 µm pore-size filter. Sources of dissolved organic carbon in streams and rivers can include leachates from soils, vegetation, algae, and human/animal waste.

Dissolved oxygen: Oxygen in the dissolved phase in water.

Ecosystem respiration (ER): Autotrophic and heterotrophic respiration (oxygen consumption). ER can increase nonlinearly with gross primary production, nutrient concentrations (nitrogen and phosphorus), organic matter availability, and temperature.

Gross Primary Production (GPP): The conversion of water and carbon dioxide to glucose (food) and oxygen in the presence of light. GPP can increase nonlinearly with light, nutrient concentrations (nitrogen and phosphorus), and temperature.

Heterotrophic respiration: Respiration (oxygen consumption) associated with the decomposition of organic matter. Bacteria, fungi, and animals are responsible for heterotrophic respiration.

Hyporheic zone: The zone below and adjacent to the stream channel (e.g., below flood plains and islands) where surface water mixes with groundwater. The hyporheic zone often is an area where a substantial fraction of ecosystem respiration occurs.

Particulate organic carbon: Organic matter that cannot pass through a 0.7 µm pore-size filter. Forms of particulate organic matter present in streams and rivers can include vegetation, wood, algae, and human/animal waste.

Dissolved oxygen listings for Mid Coast rivers, 2010 ODEQ Integrated Report

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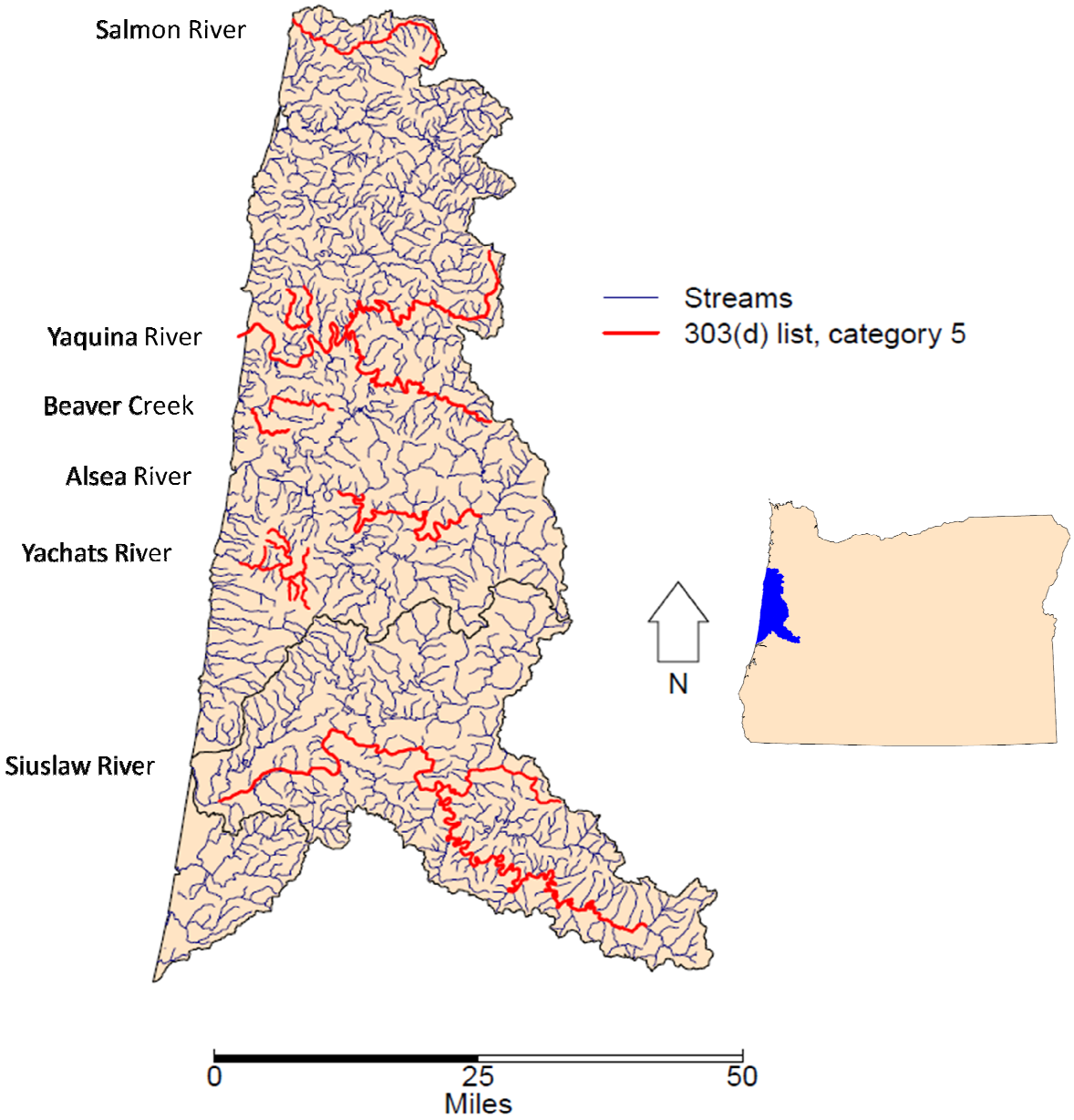

See the reverse side for tables of relevant listing criteria and specific listings.

Table 1. Relevant criteria for dissolved oxygen in Mid Coast rivers. OAR 340-041-0016.

Habitat Type	Criteria	Considered in TMDL Analysis
Spawning	≥ 11.0 mg/L or ≥ 95% saturation	If minimal intergravel DO is ≥ 8.0 mg/L (spatial median), then criterion is ≥ 9.0 mg/L
Cold Water	≥ 8.0 mg/L or ≥ 90% saturation	With adequate data, can also be ≥ 8.0 mg/L (30-day mean), ≥ 6.5 mg/L (7-day mean), or ≥ 6.0 mg/L minimum

Table 2. Mid Coast rivers listed for falling below dissolved oxygen criteria in the 2010 ODEQ Integrated Report (http://www.deq.state.or.us/wq/assessment/2010Report.htm).

River/stream	River miles	Listing Period	Criteria
Salmon River	0 – 23.1	Sep 15 – May 31	Spawning
Depot Creek	0 – 4.5	Year Around	Cold Water
Beaver Creek (Yaquina)	0 – 7.3	Oct 15 – May 15	Spawning
Beaver Creek (Yaquina)	0 – 7.3	Year Around	Cold Water
Yaquina River	0 – 26.9	Jan 1 – May 15	Spawning
Yaquina River	26.9 – 53.9	Oct 15 – May 15	Spawning
Yaquina River	0 – 56.8	Year Around	Cold Water
Big Elk Creek	0 – 5.3	Jan 1 – May 15	Spawning
Big Elk Creek	5.3 – 29.5	Oct 15 – May 15	Spawning
Big Elk Creek	0 – 29.5	Year Around	Cold Water
North Fork Beaver Creek	0 – 9.5	Oct 15 – May 15	Spawning
South Fork Beaver Creek	0 – 6	Oct 15 – May 15	Spawning
South Fork Beaver Creek	0 – 6	Year Around	Cold Water
Alsea River	15.7 – 27	Sep 15 – Jun 15	Spawning
Alsea River	27 – 47.4	Sep 1 – June 15	Spawning
Alsea River	15.7 – 47.4	Year Around	Cold Water
Williamson Creek	0 – 2.7	Oct 15 – May 15	Spawning
North Fork Yachats River	0 – 6.3	Oct 15 – May 15	Spawning
Beamer Creek	0 – 2.1	Oct 15 – May 15	Spawning
School Fork	0 – 3.2	Oct 15 – May 15	Spawning
Yachats River	3.4 – 16.6	Oct 15 – May 15	Spawning
Keller Creek	0 – 2.6	Oct 15 – May 15	Spawning
Stump Creek	0 – 2	Oct 15 – May 15	Spawning
Siuslaw River	5.7 – 105.9	Sep 15 – May 31	Spawning
Siuslaw River	5.7 – 105.9	Year Around	Cold Water
Wildcat Creek	0 – 18.8	Oct 15 – May 15	Spawning