Causes of Low Dissolved Oxygen (DO) in Basin 1 Hypolimnion of Lake Whatcom and A Proposed solution to increase DO and improve other Water Quality Properties

WWU and DOE have used data on Phosphorous, Algae, and low Dissolved Oxygen to drive the decision to increase fees to manage P out of Lake (TMDL studies). TMDL studies are missing the primary cause of Water Temperature which affects DO solubility, concentration, and availability in the warmer Summer months.

EPA recommends using Causal Analysis Diagnosis Decision Information System, or CADDIS, to help scientists and engineers in the Regions, States, and Tribes conduct causal assessments in aquatic systems. EPA Causal Analysis is based upon Kempner Trego Causal Analysis teaching (i.e., where a problem occurs vs where it does not occur; when a problem occurs vs when it does not occur, etc.) https://www.epa.gov/caddis ; https://www.epa.gov/sites/production/files/2015-12/temp-cd_sim_1500.jpg ; https://www.epa.gov/caddis-vol1/caddis-volume-1-stressor-identification-step-2-list-candidate-causes

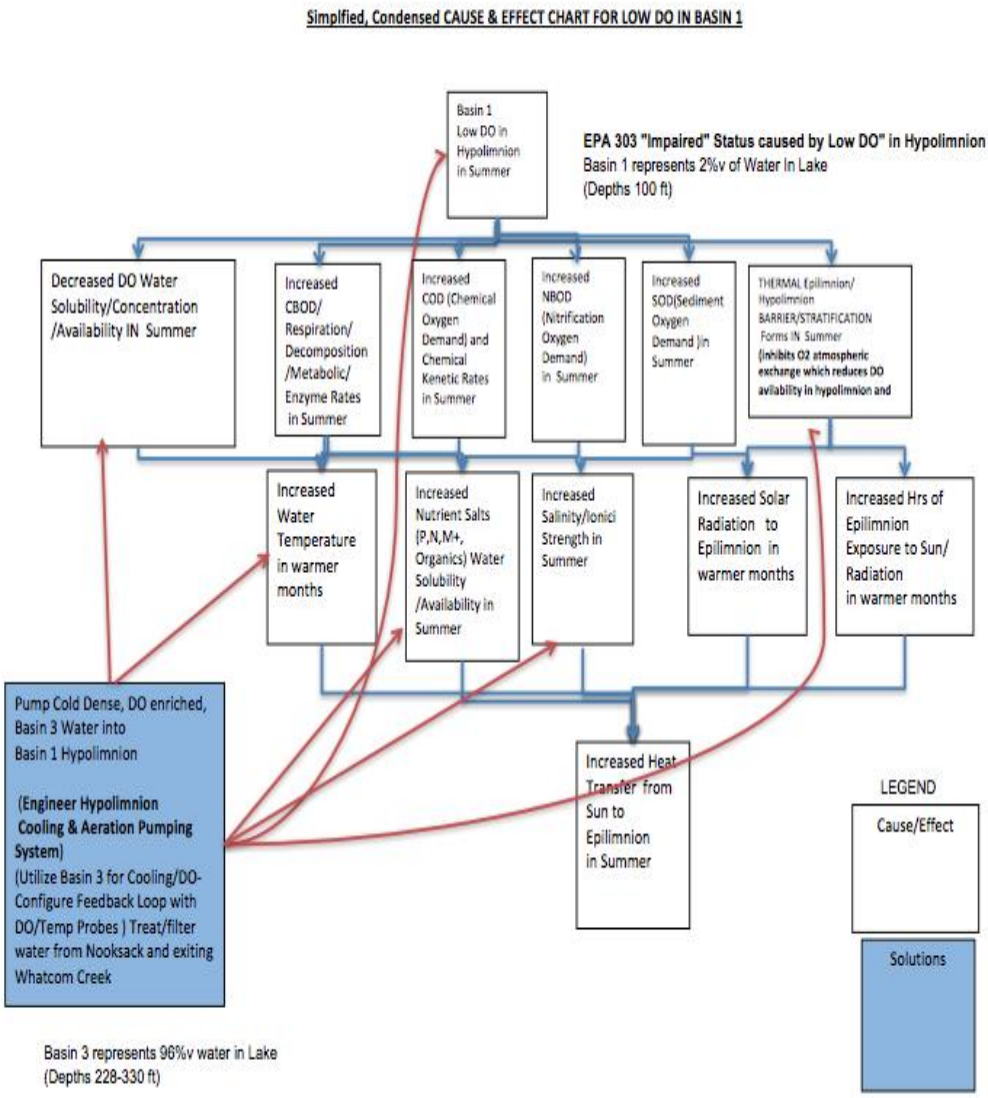


Figure 1. Causes and Effects of Low DO in Basin 1 Hypolimnion

Figure 1 depicts a Simplified and Condensed Cause and Effect Chart/Diagram which shows the causes for Low O2/DO in Basin 1. Basin 1 represents 2% of the total volume of water in Lake Whatcom.

A Cause and Effect diagram (an evidence/fact based logic tree) begins with the problem definition/statement (Primary Effect) which needs to be very specific describing the **what** (Low DO), **where/location** (Basin 1 hypolimnion),

when/time (Warmer months – Summer), and **Significance** (EPA 303 Impaired Body of Water). Once the problem is defined, the investigators begin asking "Why or Caused by" which leads to logic based development of a divergent (branched) series of causes and effects chart/diagram. Investigators keep asking why or caused by until a sufficient number of causes and effects have been determined (minimum of 5 Whys). Each **Cause/Effect** is supported with fact based, sensed evidence. **Causes** can be **condition causes** (occur over an extended period of time) or **action causes** (over a shorter period of time). **Problems occur when action and condition causes line up at the same time and in the same place/space. Effective solutions** address the majority of causes and **prevent, change, mitigate the primary effect/problem from recurring**. The most effective solution(s) address(es) the action causes.

The Low DO Cause and Effect Diagram shows the **major cause of Warmer Water Temperature** which occurs in the summer, warmer months.
DO solubility and availability are not an issue in colder water which occurs in colder, winter months.

Mother Nature manages cold water temps in winter months. The major source of O2/DO in Lake Whatcom in winter is atmospheric exchange between air and water, cold temperature, and early spring mixing caused by wind, current, and convection/conduction. Although phytoplankton and other photosynthetic plants produce O2/DO, the majority of photosynthetic O2/DO is produced in warmer water/warmer months of summer where biological and other environmental conditions are favored (i.e., increased photosynthetic rates, biological growth/reproductive rates, enzymatic rates, increased day light hours, increased nutrient salt solubility/ionic strength, etc. which are caused by warmer water temperatures.)

Heat from sun and warm weather in summer create a thermal barrier/stratification (caused by Heat transfer through conduction and convection) between the upper, epilimnion layer and lower hypolimnion layer which prevents/minimizes O2/DO exchange between epilimnion and hypolimnion and fixes a finite DO concentration in the hypolimnion layer of Basin 1. Basin 1 is 100 ft. deep and contains 2% of the total volume of water in the lake. DO solubility/availability in summer/warmer months is also affected by water temperature.

Chart 1 shows the relationship of O2 solubility vs water temperature. Colder water temperature yields higher DO solubility/availability/concentration.

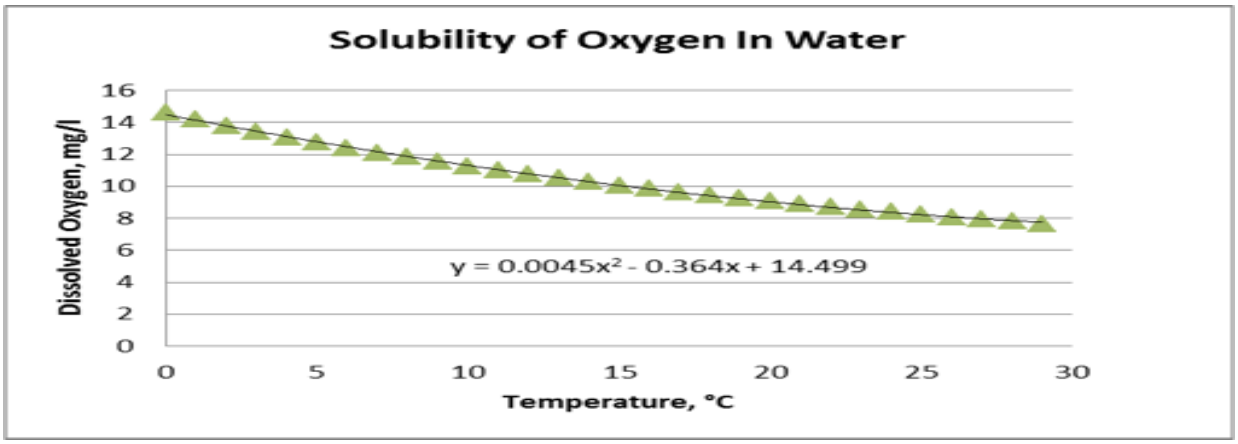


Chart 1. Solubility of O2 in Water vs Temperature

Warmer water temperature and thermal Stratification/barrier limit DO solubility/availability/concentration in Basin 1 hypolimnion in summer months. A more complete, effective solution proposal which would increase DO content in Basin 1 hypolimnion would be to pump colder, denser, O2 rich

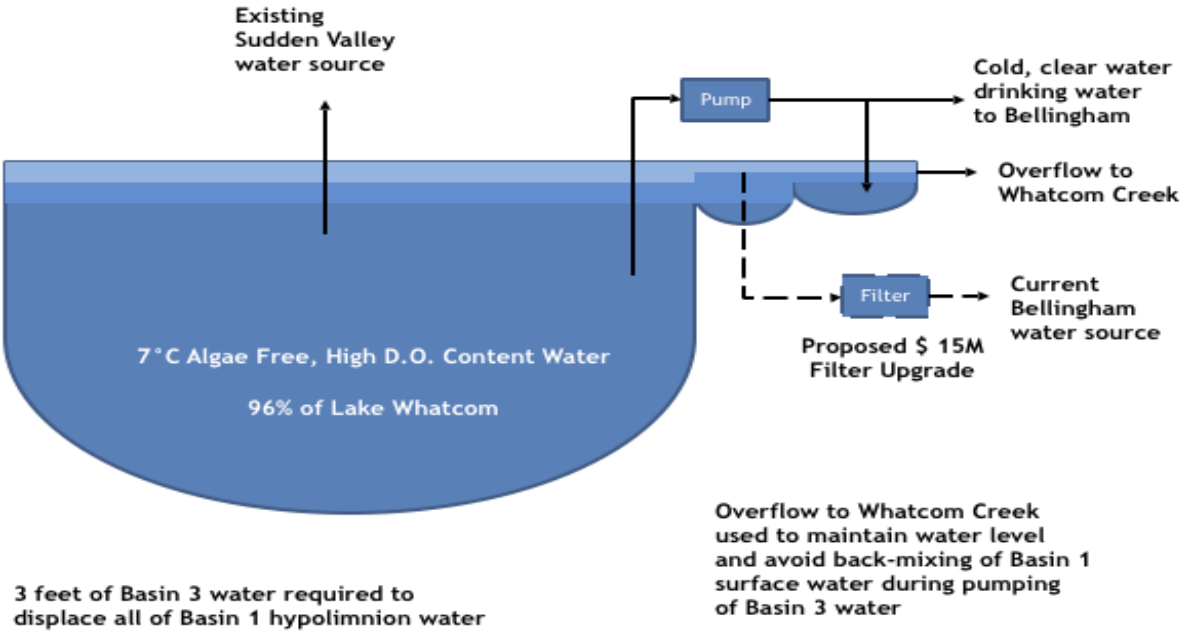
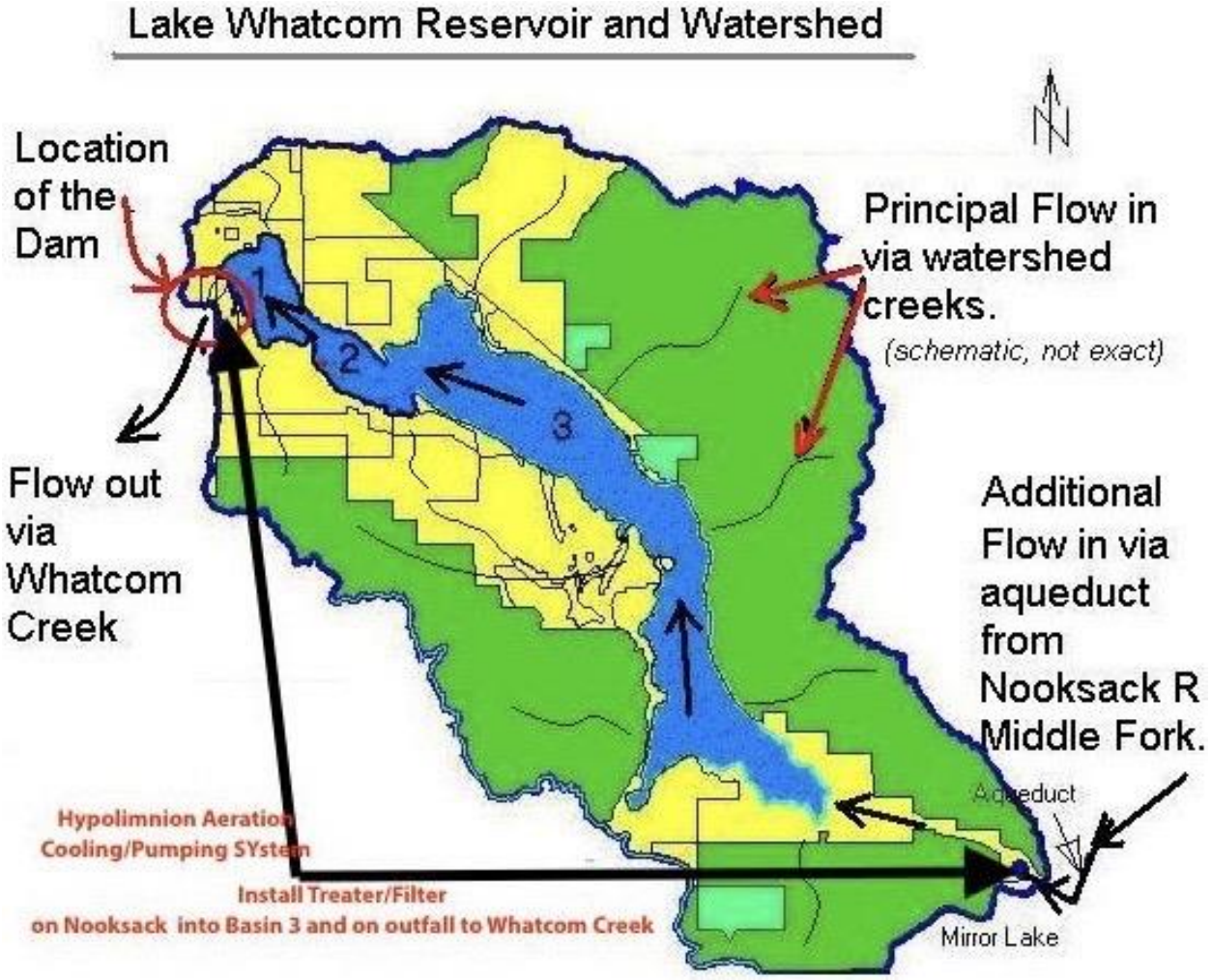


Figure 2. Pumping System Proposal for increasing DO in Basin 1

water from Basin 3 into shallower Basin 1 in summer months, mimicking the effects of cold water temperature in winter months (Figure 2). Basin 3 contains 96% of Water volume in Lake and functions as a “Heat Sink” in the lake. Basin 1

DO concentration can be improved by engineering a pumping feedback loop system with DO/temp probes inserted into various positions/depths of the Lake. Pump the denser, O2 rich water from the deeper Basin 3 into the bottom/hypolimnion of Basin 1 to levitate/displace the warmer, less dense, O2 depleted Basin 1 water and pump/manage this water out via Whatcom creek.

A Hypolimnion Cooling and Aeration system could be engineered to treat/filter cold “snow melt, Dense, O2 enriched water “entering Lake Whatcom Basin 3 from the Nooksack river and treat/filter water exiting Lake Whatcom Basin 1 via Whatcom Creek to also help manage TMDL into and out of Lake Whatcom.



We disagree with translation / interpretation that Phosphorus is the primary cause of Low O2 in Basin 1. We question whether the $50 million TMDL P decision/expenditure, now a law, to be spent in the next 5 years with a total time projection of 50 years and associated $500 million price tag (i.e., managing P and eliminate Algae respiration,

death, and decomposition) will improve Low DO concentration. Although managing/minimizing P in Lake Whatcom Watershed (TMDL) will help reduce/eliminate Algae and minimize consumption of some of the Low DO (DO depletion) in Basin 1 hypolimnion, it will not address all causes of Low DO.
There are other competing biological/biochemical/oxygen demand (i.e. aerobic (oxygen consuming, respiratory, Carbon BOD), chemistry (kinetic) processes (i.e., Chemical Oxygen Demand, Nitrification BOD, Sediment Oxygen Demand, M+ (metal oxide/hydroxide formation chemistries)
which also consume the Available DO in the hypolimnion and sediment of Basin 1in the Lake. Warmer water temperature and Thermal stratification (in summer) limit and define initial DO concentration in Basin 1 hypolimnion.

Managing P via TMDL by itself will not solve/eliminate/mitigate Low O2 concentration causes in Lake Whatcom. Managing/decreasing the temp in the shallower, lower volume Basin 1 in Lake Whatcom by engineering a Hypolimnion Cooling, Aeration, Pumping System with a DO/Temp feedback loop between the deeper, O2 rich Basin 3 water into Basin 1 hypolimnion water in late spring - early summer months will immediately improve water quality in Lake Whatcom. The costs associated with implementing and managing such a system will have to be determined but this solution will prevent/change/mitigate Low DO and solve the Low DO problem removing the EPA 303 impaired body of water classification.

Warmer Water Temperature in summer months is the major cause for Low O2 in Basin 1 Hypolimnion.

Decreasing water temp in Basin 1 hypolimnion in the Lake in late spring and early summer months will
Increase DO content immediately, prevent thermal stratification, and allow atmospheric air /water O2 exchange between all layers in Basin 1. Decreasing water temp in late spring and early summer months will also increase gas solubility (O2, CO2, etc.), lower nutrient (salts) solubility, decrease turbidity, decrease biological growth and reproductive rates, decrease metabolic rates, decrease cellular enzymatic rates, decrease photosynthetic rates, and decrease kinetic rates (chemistry/physics rates of reactions) - all observed/sensed and measured in winter/colder water temperature months (see Table1 on Water Temperature Effects on Water Quality).

Water Temperature Effects on Water Quality

Chemical/ Physical Biological Property	Decrease H2O Temperature	Increase H2O Temperature
Gas Solubility (O2, CO2)	+	-
(Nutrient) Salt Solubility	-	+
Salinity/Ionic Strength	-	+
COD (Chemical Oxygen Demand)	-	+
Kinetic Reaction Rate	-	+
Conductivity	-	+
TDS/TSS	-	+
Turbidity	-	+
Compound Toxicity (NH3, Cd, Zn, Pb, Hg)	-	+
Water Viscosity	+	-
Water Density >0 degrees C	+	-
pH H20 <> (H+) + (OH-) (IONIC)	-	+
pH H2O at 0C = 7.47 (BASIC)		
pH H20 at 25C = 7.0 (NEUTRAL)		
pH H2O at 100C = 6.14 (ACIDIC)		
Thermal Stratification	-	+
BOD (Biological Oxygen Demand)	-	+
Biological Growth Rate	-	+
Biological Reproduction Rate	-	+
Photosynthesis Rate	-	+
Cellular Enzyme Activity Rate	-	+
Metabolic Rate	-	+
Respiration Rate/O2 Consumption Rate	-	+
Digestive Response	-	+

Effects
(+) = Increase
(-) = Decrease

The above Table 1 was created from data listed in Fondriest Environmental, Inc.: Water *Temperature." Fundamentals of Environmental Measurements. 7* Feb. 2014. Web. < http://www.fondriest.com/environmental-measurements/parameters/water-quality/water-temperature/ >.

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