Benefits and optimization of hypolimnetic withdrawal as a lake restoration technique

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and to People involved in HW:

- Johanna Ansker, Stockholm Vatten
- Al Sosiak, MOE Alberta
- Dick Lathrop, MOE Wisconsin
- Harry Gibbons, Seattle Washington
- Roland Psenner, Austria
- Julita Dunalska, Poland
- Špela Rekar, Slovenia
- Michael Hupfer, Germany
- Ingrid Chorus, Germany
- Rene Gächter, Switzerland
- Pius Niederhauser, Switzerland

Outline

- HW Principle: decrease the effect of internal P loading
- Importance of hydrology and timing
- Benefits re trophic state
  - Phosphorus (P)
  - Phytoplankton, Cyanobacteria
  - Anoxia
- Potential problems
  - In lake: warming of hypolimnion, destratification
  - Downstream: Treatment of withdrawal water

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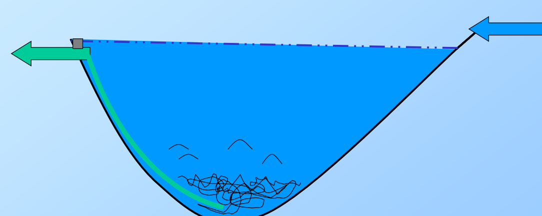
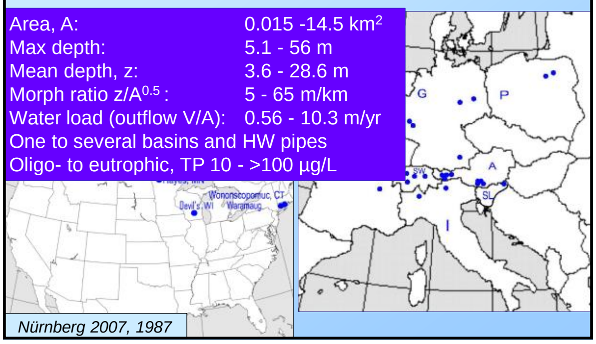
Underused lake restoration treatment:
Hypolimnetic Withdrawal (HW)
"Better" lakes in the Great Lakes' watershed benefit the GL water quality.



HW Locations

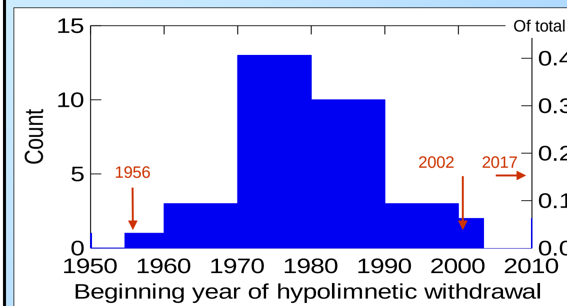
North America: 8 — Europe: ~40 known

Area, A: 0.015 -14.5 km^2
Max depth: 5.1 - 56 m
Mean depth, z: 3.6 - 28.6 m
Morph ratio z/A$^{0.5}$: 5 - 65 m/km
Water load (outflow V/A): 0.56 - 10.3 m/yr
One to several basins and HW pipes
Oligo- to eutrophic, TP 10 - >100 µg/L



Nürnberg 2007, 1987

HW Projects started in 1956

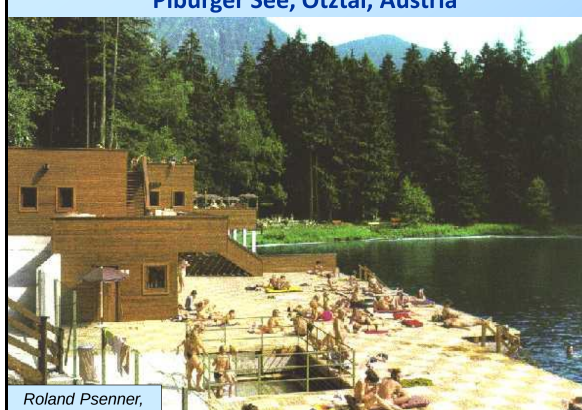


Piburger See, Austria, passive HW since 1970

Surface area	264 ha
Max. depth	24.6 m
Mean depth	13.7 m
Residence time	1.9 years
Surface elevation	913 m

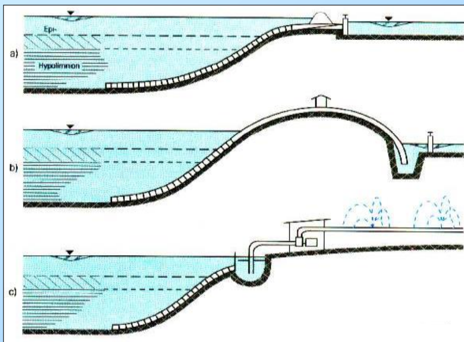
Roland Psenner, pers. comm.

Piburger See, Ötztal, Austria



Roland Psenner, pers. comm.

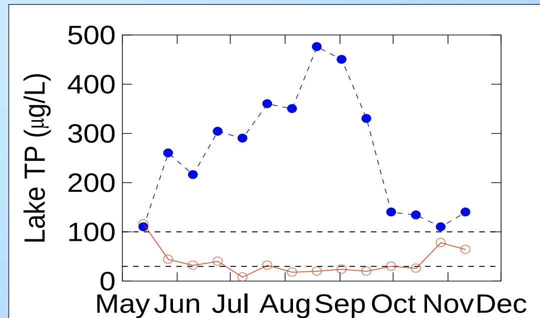
Siphoning by gravity, irrigation



Klapper 1985, Anwenderrichtlinie … Tiefenwasserableitung, German EPA

Typical TP distribution in stratified lake

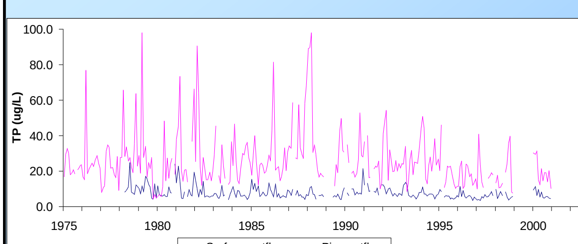
Surface and Bottom TP in Lake Wilcox, ON, 1997



HW Goal: Enhanced Phosphorus Export

Piburger See, Austria, passive HW started 1970

Surface outflow compared to HW outflow TP concentration



Roland Psenner, pers. comm.

Principal: Maximize P export to decrease the effect of internal loading

- Maximize withdrawal volume w/o drawing down the lake (***hydrology***).
  - Naturally high water loads
  - Artificially enhance flushing
- Adjust **timing** to withdraw in late summer and fall, when concentrations of nutrients and reduced substances are highest.

Maximize P export

Devil's Lake, Wisconsin, start 2002

q_s= 1.18 m/yr before

- Divert clean water from intermittent stream during spring

Withdrawal Pipe

Diversion Pipe

Intermittent Stream Draining NE Bluff

- Withdraw from mid-September to mid-October flow rate: 0.11-0.17 $m^3\ sec^{-1}$

Dick Lathrop, pers. comm.

Dependency on hydrology

Annual variation of flows (case studies)

- Pine Lake, Red Deer, Alberta
  Annual precipitation ~490 mm
  HW possible 7 of 10 years (70%) based on historic rainfall, actual 4.5 of 7 yrs (64%).
- Lake Kortowskie, Poland, Baltic catchment
  Annual precipitation >600 mm
  Potential benefit for climate change induced summer rain storms: In wet year 2011, more input, more water available for outflow, higher P export compared to long-term average.

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Results: Water quality benefits due to HW

- Decline of TP: yes, related to TP export via HW
- Decline of phytoplankton as Secchi, chlorophyll, cyanobacterial blooms: yes/indications
  - Metalimnetic cyanobacteria declined
  - Surface bloomers (harmful algal blooms, HABs)
- Decline of anoxia: after a lag, but eventually

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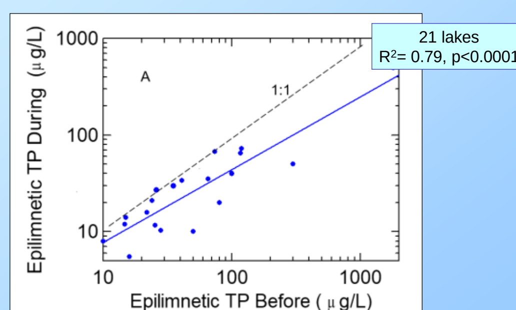
Case studies: Epilimnetic TP – before versus during HW



Nürnberg 2007

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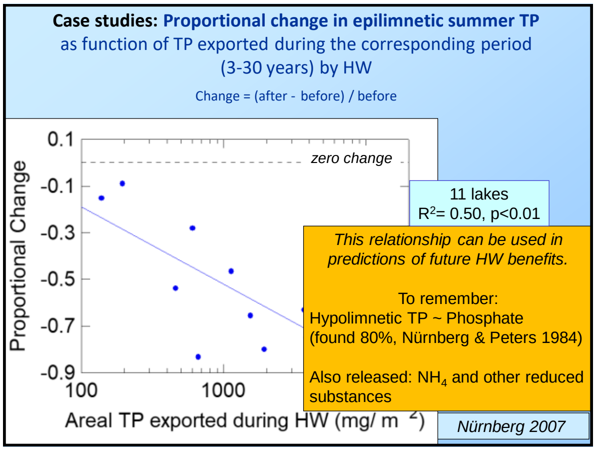
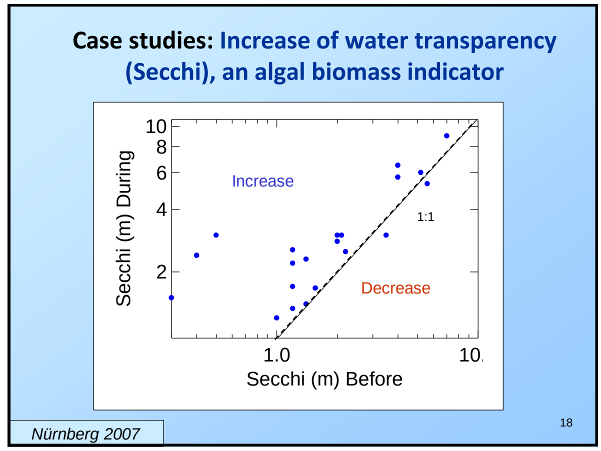
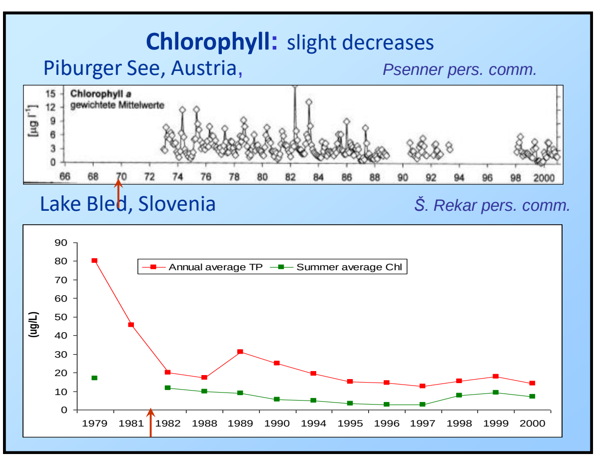
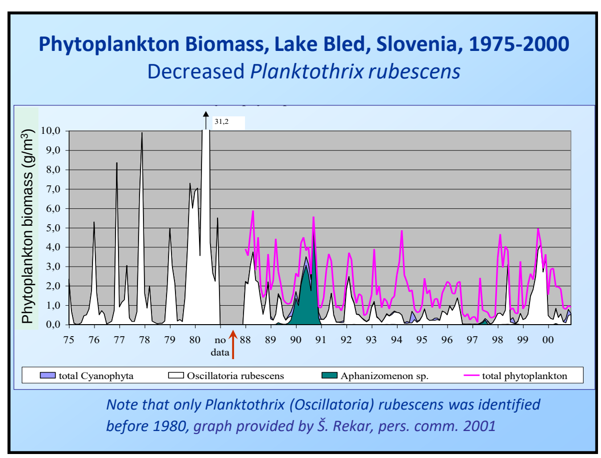

Case studies: Proportional change in epilimnetic summer TP
as function of TP exported during the corresponding period
(3-30 years) by HW
Change = (after - before) / before
zero change
11 lakes
R²= 0.50, p<0.01
This relationship can be used in predictions of future HW benefits.
To remember:
Hypolimnetic TP ~ Phosphate
(found 80%, Nürnberg & Peters 1984)
Also released: NH4 and other reduced substances
Proportional Change
0.1
-0.1
-0.3
-0.5
-0.7
-0.9
100
1000
Areal TP exported during HW (mg/ m ²)
Nürnberg 2007


Case studies: Increase of water transparency
(Secchi), an algal biomass indicator
Secchi (m) During
10
8
6
4
2
Increase
1:1
Decrease
1.0
10.
Secchi (m) Before
18
Nürnberg 2007


Chlorophyll: slight decreases
Piburger See, Austria,
Psenner pers. comm.
Chlorophyll a
gewichtete Mittelwerte
[µg l⁻¹]
66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 2000
Lake Bled, Slovenia
Š. Rekar pers. comm.
Annual average TP
Summer average Chl
(ug/L)
1979 1981 1982 1988 1989 1990 1994 1995 1996 1997 1998 1999 2000


Phytoplankton Biomass, Lake Bled, Slovenia, 1975-2000
Decreased Planktothrix rubescens
Phytoplankton biomass (g/m³)
31,2
75 76 77 78 79 80 no data 88 89 90 91 92 93 94 95 96 97 98 99 00
total Cyanophyta
Oscillatoria rubescens
Aphanizomenon sp.
total phytoplankton
Note that only Planktothrix (Oscillatoria) rubescens was identified
before 1980, graph provided by Š. Rekar, pers. comm. 2001

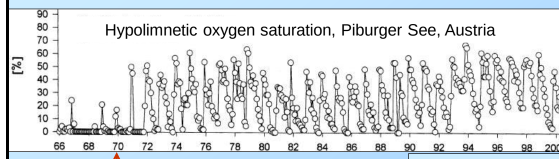
HW reduced metalimnetic blooms (*Oscillatoria, Planktothrix*) adapted to low light and cool temperature in at least 5 European and NA lakes

- **HW** removes
  - Cells directly?
    Unlikely, pipes are close to bottom, not metalimnion
  - Nutrients
    Most likely, accumulation of nutrients in hypolimnion (Hypothesis also favoured by René Gächter for Mauensee, Switzerland)

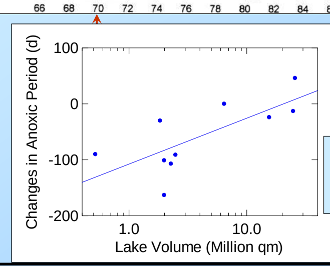
Gächter, V. R. 1976. *Swiss J. Hydrol.* 38: 1–29
Nürnberg et al. 2007, *Lake & Reserv Manage*

Under ice, *Lake Wilcox, ON, 2000*

Hypolimnetic Oxygen



Psenner, pers. comm.



Changes in anoxic period with lake volume: 10 lakes
$R^2 = 0.54$, $p<0.015$

Potential HW-related problems in the lake

- Hypolimnetic temperature increase
  - Enhances P release
    P release rate increases by a factor of 2-7 for every 10 °C increases (Q10 rule, *e.g., Liikanen et al. 2002*)
  - Enhances oxygen depletion
    Sediment oxygen demand increase by 6.8 % per °C (*e.g., Livingstone and Schanz 1994)*
  - Induces early fall turnover
- Case study: No increase in hypolimnetic summer temperature at withdrawn water load < 1 m/yr (in 6 lakes)

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Downstream Effects

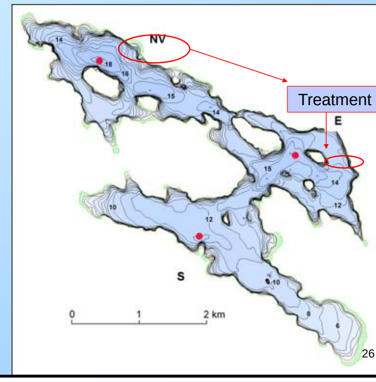
- Possible benefits - Decreases in
  - Temperature
  - Phytoplankton biomass
  - Turbidity

Downstream Consequences and Treatment

- Possible problems
  - Reduced substances (Anoxia, H_2S, odour)
  - Increased nutrients (Phosphate, Ammonia)
- Treatment options
  - Anoxia: Fountain aerator
  - Smelly gas, H_2S: Building & diversion
  - Nutrient: Settling basin
  - Diversion and treatment in wastewater treatment plant
  - Dilute with surface water
  - Elevate withdrawal intake
  - Decrease and discontinue withdrawal

Bornsjön, *Stockholm Vatten*, Sweden, Source water treatment plant, 2017

- 2 month HW From NV, 17m, (4.5 km pipe) to treatment, into E-basin, 11m
- 10 month drinking from E, 11m



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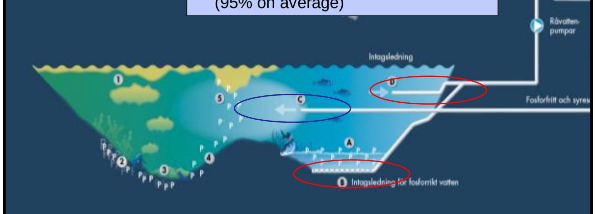
Bornsjön, Stockholm, Sweden 2017

STOCKHOLM VATTEN OCH AVFALL

Construction and performance details
- 2.5 yrs from drawing board to finish
- 20 mill Euros to build
- "Surprisingly" effective P removal (95% on average)



Johanna Ansker, Stockholm Vatten, pers. comm.

Kymijärvi, Finland, 2018

- Experimental stage
- Hypolimnetic TP = **3 x** epilimnetic TP
- Remove water, treat, and return
- Treatment with $CaOH_2$ filters that allow P recovery, and wetland

Jukka Horppila, pers. comm.

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Reservoirs

- Many reservoirs operate with deep water release that help reservoir water quality, even if it's not deliberate (e.g., Cherry Creek Lake in Denver, Colorado).
- Different Goals via water column destabilization and prevention of stagnant conditions:
  - Improve hypolimnetic and withdrawal water (especially in drinking water reservoirs)
  - Decrease surface HABs (Ford Lake, Eau Galle reservoir)

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Challenges in HW Praxis

- Lack of water (inflow augmentation)
- Outflow is of wastewater quality (treatment)
- Accidental destratification (add cool water at depth, regulate outflow)
- Needed stratification (deep hole)
- Short stratification period (in northern lakes, but may increase with climate change)
- Beaver damming the outflow (management, re-routing)
- Floating pipe(add weights)
- Lack of long-term commitment

What is crucial for the success of HW?

- **Bottom TP >> surface TP**: stratified, deep hole, not polymictic
- **Hydrology – enough water to operate during summer and fall:** high water load q_s
  Remedy: inflow augmentation, recycling after treatment
- Space and support for **withdrawal treatment** to protect downstream water

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