A Discussion Related to Legacy Nutrients and their Potential Influence upon the Ecology of the San Francisco Peaks and Contiguous Areas

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## REVIEW

In a 2018 paper, Chen et. al[2] note that legacy nutrients may be considered surplus anthropogenic (human originated) nutrient inputs from previous years that are temporarily stored within the watershed and have the potential to contribute nutrients to the atmosphere, biomass, and waters. While the term legacy nutrients is relatively new, the concept that stored or sequestered nutrients—primarily Nitrogen and Phosphorus—can influence the rate, timing and type of primary production associated with an ecosystem has been a subject of interest with ecologists for well over seventy years, and with agronomists even longer. Legacy nutrients are of particular concern within watersheds whose ecological stability is sustained by a relative paucity of nutrients. Such low nutrient (oligotrophic) systems have through the process of natural selection (i.e. selective advantage) limited their collection of primary producers (e.g. autotrophic organism such as green plants and algae) to those able to subsist and thrive in oligotrophic environments. Any influx of nutrients into these oligotrophic systems which far exceeds the historical rate of influx can cause disruptions to the ecology, resulting in shifts in the rate of primary production and in the species composition and diversity of these producers.

Freshwater lakes and estuaries have typically received the most attention regarding ecological disruption through excessive nutrient loading from anthropogenic sources, including the loading from legacy nutrients. These disruptions have caused serious impairment of these resources by stimulating production of invasive plants and suspended algae (phytoplankton)—a process known as eutrophication. Around the time of the passing of the Clean Water Act in 1972 (PL-92-500), several of the Great Lakes had become eutrophic as measured by high levels of phytoplankton production. These lakes had experienced heavy anthropogenic nutrient loading for years, which was identified as the cause of the eutrophic conditions. But it was also recognized that much of the loading may have been quasi-sequestered for some time, with the release to the water column coming later from these quasi-sequestered or legacy stores, such as those held within the lake sediments. Hence several studies were conducted on the nature of anthropogenic nutrient loads held within the lake sediments and the processes involved with the movement of these nutrients within the sediments and from the

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[2] Dingjiang Chen, Hong Shen , Mingpeng Hu, Jiahui Wang, Yufu Zhang, Randy A. Dahlgren (2018) Chapter Five - Legacy Nutrient Dynamics at the Watershed Scale: Principles, Modeling, and Implications. IN Advances in Agronomy Volume 149;237-313

sediments to the overlying water[3]. It was noted that anthropogenic phosphorus loads coming into the lake could be initially directed to the sediments through adsorption, chemical bonding, and settling of suspended solids. Bound sediment phosphorus however was noted to become more mobile with shifts in certain environmental conditions such as pH and Redox potential. and as eddy currents and other disruptive forces cause mixing with the overlying water. Therefore the influence of excessive phosphorus loading from external sources, e.g. wastewater effluent, may not be immediately manifested as eutrophic level algae blooms[4]. Instead these loads may be initially lost to the sediments or to other biota, only later moving into the water column where they can elicit heavy phytoplankton production. Hence the impact of legacy loading can delay the influence of initial nutrient loading on primary production.

As an example, the University of Florida[5] calculated the legacy phosphorus load within the Lake Okeechobee watershed is about 100,000 metric tons, or enough to provide 500 metric tons to the lake for 200 years. Even if no additional external loads contributed to the lake, the conditions would remain eutrophic for two centuries because of these legacy loads.

The nature of legacy phosphorus in Lake Okeechobee was also studied by Missimer et.al.[6] who describe the organic “muds” in Lake Okeechobee as incorporated into three layers—a consolidated bottom layer, a less consolidated mobile middle layer, and a thixotropic layer, i.e., readily fluidized, which moves both laterally and vertically under the direct influence of wind and wind-induced currents (e.g., seiches). It is this top fluid layer that apparently serves to reintroduce available legacy nutrients to the water column, and which feeds the frequent blooms of Cyanobacteria. The age of this thixotropic layer has been estimated at seventy-two years, indicating it is the result of anthropogenic activities. They note further that the sediments in Lake Okeechobee (fluid mud), which have accumulated from decades of inflow from the watershed and from herbicide destruction of in-lake vegetation growth serve as a semi-permanent source of the key nutrients that can support and sustain these extensive (Cyanobacterial) blooms. Despite major efforts to control external nutrient loading into the lake, the high frequency of algal blooms will continue until the muds bearing legacy nutrients are removed from the lake.

Similar legacy nutrient conditions have also been noted within Florida’s Indian River Lagoon—an estuary of national importance. It has been estimated that about 30% of

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[3] Williams, J.D.H. and T. Mayer (1972) “Effects of Sediment Diagenesis and Regeneration of Phosphorus with Special Reference to Lake Erie and Ontario” IN Nutrients in Natural Waters edited J.R. Kramer and H.E. Allen . Jon Wiley & Sons New York p256

[4] These heavy algae blooms are often called Harmful Algae Blooms or HAB and may involve toxic blue-green algae known as Cyanobacteria.

[5] University of Florida, Water Institute, W. Graham Director. (2015) Options to Reduce High Volume Freshwater Flows to the St. Lucie and Caloosahatchee Estuaries and Move More Water from Lake Okeechobee to the Southern Everglades An Independent Technical Review . Gainesville, Florida

[6] Missimer, T.M.; Thomas, S.; Rosen, B.H. (2021) Legacy Phosphorus in Lake Okeechobee (Florida, USA) Sediments: A Review and New Perspective. Water 13, 39. https://doi.org/10.3390/w13010039

the nutrient loading to the lagoon is from legacy nutrients[7]. As with Lake Okeechobee, these legacy nutrients will likely impede any long-term efforts towards restoration. As a result of legacy nutrients as well as heavy external loading, the Indian River Lagoon has shifted from a seagrass dominated primary production to a phytoplankton dominated system. As a result, in 2021 over 1,100 threatened manatees, which rely upon seagrass as a food source during the winter months, perished from starvation[8].

Nitrogen legacy stores within groundwaters is also a serious concern. In recent years these legacy nitrogen stores have released excessive amounts of nitrate nitrogen into Florida's springs, causing shifts in primary production from submerged vascular plants to potentially toxic benthic blue-green algae (Cyanobacteria). This in turn has resulted in other biotic changes. Two major sources of this excess legacy nitrogen is from reuse of domestic wastewater effluent and septic tank leakage[9].

## LEGACY NUTRIENTS POTENTIAL IMPACT ON SAN FRANCISCO PEAKS

There are many other examples of how legacy nutrients have impaired water resources. However, legacy nutrients can also impact the biotic composition of terrestrial ecosystems, particularly those associated with low nutrient inputs,  including alpine and subalpine ecosystems as those associated with Arizona's San Francisco Peaks and the associated Snow Bowl Sub Area and Harts Prairie. As noted within a USDA Forestry Service[10] report, nitrogen loading can "*drive changes in entire communities and adversely affect ecosystems, by shifting plant composition in habitats important to threatened and endangered species, favoring invasive plant species, increasing fire frequency and intensity, impacting ecosystem health, and decreasing biodiversity."* Such nitrogen loading may come from legacy stores from the atmosphere, as well as legacy stores within groundwaters, sediments or within artificial snow produced from nutrient enriched wastewater effluent. Snow generated from wastewater effluent may be considered a legacy source, as it is temporarily stored, being released during seasonal snow melt.

Considering the potential of legacy nutrient loading upon alpine and subalpine ecosystems as well as upon downgradient surface waters such as springs known as tanks, the influence of legacy nutrient loading from snow melt associated with effluent manufactured snow at the Snow Bowl Facility should be seriously evaluated.

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[7] Fox, A.L. and J.H. Trefry (2018) Environmental Dredging to Remove Fine-Grained, Organic-Rich Sediments and Reduce Inputs of Nitrogen and Phosphorus to a Subtropical Estuary *Marine Technology Society Journal July/August 2018 Volume 52 Number 4*

[8] Florida Fish and Wildlife Conservation Commission, Marine Mammal Pathobiology Laboratory 2021 Preliminary Manatee Mortality Table with 5-year summary 2/2/17- 5/2022

[9]Moira R. Homann (2018) Florida Department of Environmental Protection (2018) Wekiva River, Rock Springs Run, and Little Wekiva Canal Basin Management Action Plan (BMAP)
March 8, 2018

[101010]Pardo, L.H., T. Blett, C.M. Clark and L.H. Geisa (2015) Impact of Nutrient Pollution on Terrestrial Ecosystems in U.S. USDA Forestry Service

In a 2021 independent review of nutrient loading changes to the Snow Bowl Sub Area and contiguous areas related to the use of wastewater effluent for snowmaking, Stewart[11] estimated the change in nitrogen loading from 10,875 pounds annually to 23,018 pounds annually as a seasonal average or a 112% increase. This additional loading would likely impede the fixation of atmospheric nitrogen within the alpine and perhaps the subalpine systems, and possibly result in loss of indigenous plants which depend upon nitrogen fixation to provide a selective advantage.

Phosphorus loading changes were even more dramatic than nitrogen, increasing from 1,464 pounds annually to 7,068 pounds annually as a season average or a 383% increase. While it might be argued that phosphorus may not be limited within the soils associated with the San Francisco peaks, such a large increase, particularly if the phosphorus is in the soluble ortho-phosphorus form, could elicit species shifts within these sensitive ecosystems.

The application of effluent through snowmaking presents two concerns related to environmental disruption. The first is associated with surface runoff from snowmelt which threatens both the alpine systems and the subalpine areas such as Harts Prairie. It is prohibited through the Arizona Department of Environmental Quality, R1809-704 of water quality standards to allow *runoff of reclaimed water or reclaimed water mixed with stormwater from a direct reuse site.* However, Hereford[12] in an independent study documented the discharge of stormwater runoff from the Snow Bowl site to Harts Prairie. It is not known if this runoff includes residual effluent from the snowmaking activities. Therefore it is suggested that a comprehensive study be conducted to determine if such residuals exist.

The presence of wastewater effluent can be confirmed through nitrogen isotope ratios and the presence of markers such as sucralose (artificial sweetener) as described by Herren et. al.[13]. This methodology can be applied to determine the fate of effluent and effluent residual by establishing strategic sampling points and methodologies from upgradient to downgradient stations both as surface waters and where appropriate, groundwaters. Testing would include as a minimum background condition prior to snowmelt, and active conditions during snowmelt. It may also include testing immediately following significant rainfall events.

There can be little question that the heavy nutrient loading from the use of wastewater effluent for snowmaking on the Snow Bowl Facility may have immediate and legacy

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[11] Stewart, E.A. (November 2021) Concerns Regarding Increased Nutrient Loading Proposed for the use of Wastewater Effluent for Snowmaking at the Snow Bowl Facility on the San Francisco Peak, Arizona email eas@pasop.org to obtain a copy of this report.

[12] Richard Hereford, research geologist emeritus (2023) Documented Stormwater Runoff Beyond Arizona Snowbowl's Permit Area Causes Erosion and Pollution of Hart's Prairie Ecosystem. To request a copy of this report contact Richard Hereford at richardhereford@msn.com

[13] Herren, L.W.; R.A. Brewton; L.E. Wilking; M.E. Tarnowski; M.A. Vogel and B.E. Lapoint (2021)Septic systems drive nutrient enrichment of groundwaters and eutrophication in the urbanized Indian River Lagoon, Florida Marine Pollution Bulletin 172 (2021) 112928

based long-term influence on the ecological stability of the associated alpine and subalpine ecology of the region. A comprehensive testing and monitoring program is necessary to determine the nature and extent of this influence.