A Brief Review of Concerns Related to Nutrient Loading on Critical Habitats within the SnowBowl Area of the San Francisco Peaks Related to the Use of Reclaimed Wastewater for Snowmaking

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The modern biological discipline of Ecology is relatively new, having emerged in the late nineteenth century. Ecology literally means study of our home from the Greek word Oikos for home, and --ology referring to objective study. Even more recently, Systems Ecology has emerged as a subdiscipline, bringing emphasis to the complex interactions of living and nonliving components of an ecosystem, and specifically to the flow of materials and energy by which dynamic equilibrium is established. We now know that an ecosystem's ability to sustain itself relies upon conditions fluctuating within a range of historical perturbations related to such things as weather, seasonal changes, scheduling, photoperiod, atmospheric influences, drought, fire, flooding and migration of various plants and animals. Over time the collection of plants and animals which adapt to, and benefit from these perturbations, establish the character of an ecosystem, and through the evolved stability provide valuable resources. For the most part, aboriginal indigenous peoples prior to the influx of the European newcomers understood the importance of protecting the stability of their environment and the ecosystems that provided them food, water, medicines, weaponry, transportation, clothing, shelter, utilities, and spiritual health. I have heard this understanding expressed as the "Creator's Law" and these societies realized how critical abiding by this law was to their welfare.

Put in scientific terms we might think of the Creator's Law as the warning that if an ecosystem is disrupted far beyond its experienced range of perturbations, it could be thrown out of its dynamic equilibrium, which is out of balance, and the resulting changes could be unpredictable and potentially irreversible. As our populations have increased and industry and technology have expanded we have seen far too many examples of how such large-scale disruptions have caused severe damage to some of our most cherished ecosystems. Some of these cases involve the reduction of critical species, such as the elimination of the grey wolf from Yellowstone, which allowed expanded grazing by a growing elk population, which resulted in erosion and loss of water quality. In the Northeast US, destruction of habitat reduced the number of predators such as foxes, owls and snakes which controlled the population of white-footed mice, which hosts the tick which carries Lyme's disease. Population explosion of this mouse has resulted in a notable outbreak of Lymes disease.

Perhaps of all of the major disruptions imposed upon our environment, one of the most destructive has been the high rate of nutrient influx—that is nitrogen and phosphorus—into vulnerable ecosystems. In Florida for example, discharge of these nutrients from wastewater effluents, urbanization and agriculture have promoted excessive growth of cyanobacteria or blue-green algae which develop as toxic blooms which threaten human health as well as the health of fish and wildlife. In addition these blooms shade out sunlight which is critical to the growth and health of essential submerged grasses which support the diverse collection of organisms essential to the ecological health of Florida's lakes, springs, and estuaries. For example, recent loss of these grasses in the Indian River Lagoon—one of the most productive ecosystems in the United States—resulted in the starvation of over one thousand threatened manatees that feed on these grasses. Nutrient loads in Florida have also promoted blooms of the red tide organism in Florida's Gulf Coast, resulting in massive fish kills while creating respiratory health problems and impacting the State's critical tourism industry. In other regions, heavy nutrient loading in Lake Erie has resulted in Harmful Algal Blooms or HAB's and have negatively impacted drinking water sources for cities such as Toledo, Ohio.

But deleterious impacts of nutrients is not limited to just water quality degradation. Over fertilization with nitrogen and phosphorus can impact vulnerable terrestrial systems as well. For example alpine systems such as those associated with parts of the SnowBowl region which are characterized by thin oligotrophic (low nutrient) soils have the potential of being significantly affected by atmospheric nitrogen deposition and acidification associated with the expanding urbanization. It has also been shown in numerous studies that increased inputs of nitrogen cause adverse effects on terrestrial and aquatic ecosystems as well as human health, through impacts on air, soil, and water quality. The best quantified adverse impacts include the loss of plant diversity in terrestrial ecosystems and excess algal growth in aquatic ecosystems.

In a 2015 study jointly authored by the USDA Forest Service, the US Parks Service and the USEPA, entitled Impacts of Nitrogen Pollution on Terrestrial Ecosystems in the United States it was noted that elevated nitrogen deposition disrupts the normally tight nitrogen cycle of natural ecosystems resulting in changes in how the ecosystem behaves. For example, nitrate in soil that leaches into ground and surface waters may affect water quality downstream and may also acidify lakes and streams to the extent that many species of fish cannot survive. Excess nitrogen deposition can also alter the physical structure of terrestrial ecosystems, for example, favoring fast-growing invasive species over native species, which can increase the plant material available to fuel wildfires and lead to increased frequency of fires, posing a risk to human structures and wildlife habitat. In other studies it has been observed that anthropogenic—meaning of human source—nitrogen and phosphorus inputs impact natural environments and have far-reaching ecological and evolutionary consequences.

Considering the abundance of confirmed evidence that excessive nutrients can deleteriously alter ecosystems, whether aquatic, estuarine, marine of terrestrial, it must be considered prudent to consider the potential damage which might occur when wastewater effluent is deposited on sensitive alpine and subalpine ecosystems associated with the San Francisco peaks. This concern gains legitimacy when it is recognized how important this region is to the Indigenous cultures which have relied upon the associated ecosystems for centuries.

There are two issues related to the use of wastewater effluent for snowmaking that require additional attention and further testing and monitoring. The first is whether effluent or effluent associated residuals are mixing with stormwater runoff or groundwater seepage and are leaving the SnowBowl boundaries. The second is whether the quantity of additional nutrients applied with the wastewater effluent used for snow production are of sufficient magnitude to be considered a significant disruption to initial conditions, and hence a serious threat to the ecological stability.

Within a 2022 investigative report, Richard Hereford et.al.[1] identified evidence of heavy stormwater runoff discharges, attendant with significant erosion, leaving the SnowBowl boundary into the

[1] Hereford, R.; Brownold T.; and Waring, G. (2022) Hydrology and Water Quality of Surface Runoff onto Hart Prairie from Arizona Snow Bowl, Coconino National Forest—Results and Preliminary Interpretations, 12 p., 1 Table, 5 figs. W*ith Addendum* Documentation of Runoff and Its Effects on Hart Prairie and Developmental Chronology of Stormwater Drainage System, 20 figs.

downgradient Hart Prairie watershed. This runoff was laden with both nitrogen and phosphorus, most of which was associated with the eroded soil. Of question is whether a portion of this nitrogen and phosphorus finds it origins with the wastewater effluent used for snowmaking. This can be determined using techniques related to ratios of nitrogen isotopes characteristic of wastewater, and the presence of the wastewater effluent marker sucralose, which is an artificial sweetener. These techniques have been applied effectively by Dr. Brian LaPointe of Harbor Branch Institute and Florida Atlantic University in Ft. Pierce Florida. It is suggested Dr. LaPointe and his staff be involved in investigations of the SnowBowl water and soil quality to determine the presence of these wastewater effluent indicators.

Discharge of stormwater runoff mixed with wastewater effluent would be in violation of the water quality standards for the Arizona Department of Environmental Quality (ADEQ)—Water Quality Standards *R18-9-704:G. Prohibited Activities (3) misapplying reclaimed water for any of the following reasons: c. allowing runoff of reclaimed water or reclaimed water mixed with stormwater from a direct reuse site.*

Similarly, groundwater discharges of effluents are also restricted per *49-241 Permit required to discharge; B. Unless exempted under section 49-250, or unless the director determines that the facility will be designed, constructed and operated so that there will be no migration of pollutants directly to the aquifer or to the vadose zone, the following are considered to be discharging facilities and shall be operated pursuant to either an individual permit or a general permit, including agricultural general permits, under this article:*
1. Surface impoundments, including holding, storage settling, treatment or disposal pits, ponds, and lagoons..
9. Sewage treatment facilities, including on-site wastewater treatment facilities.

It is worth noting that the effluent quality established by ADEQ for reclaimed water does not specifically address the issue associated with ecological impacts of nutrients, and consequently approved effluents are comparatively high in nutrients—with no limits cited for phosphorus.

The second issue cited relates to whether the nutrient loading increase due to snowmaking is high enough to cause ecological degradation. Considering the wastewater treatment method used at the Rio de Flagg wastewater treatment facility, it was estimated the reclaimed effluent levels would be 6 mg/L for total nitrogen and 3 mg/L for total phosphorus. Reasonable literature values were used to estimate pre-snowmaking inputs from the atmosphere. An analysis completed in 2021[2] provides comparative nutrient loading rates before and after the application of reclaimed wastewater for snowmaking. For nitrogen, pre-snowmaking, the average annual load over the 1,061 acres of the SnowBowl Subarea, excluding nitrogen fixation, was estimated at 2,044 pounds. When snowmaking is considered the average annual load increases to 8,115 pounds, or about 297% increase. While nitrogen fixation rates are difficult to project, based upon literature information, nitrogen fixation within the SnowBowl Subarea could add an additional 14,250 pounds of nitrogen per year. Even when this nitrogen fixation is considered there is still a significant increase of 37% attendant with the snowmaking option. Changes in annual average phosphorus loads are even higher, increasing from 256 pound per year for the pre-snowmaking scenario, to 3,058 pound per year after snowmaking is implemented, or an increase of 1,095%.

[2] Stewart, E.A. (2021) Concerns Regarding Increased Nutrient Loading Proposed for the Use of Wastewater Effluent for SnowMaking at the Snow Bowls Facility on San Francisco Peaks, Arizona.

Some may find it difficult to grasp the potential impact of these increases, so perhaps an analogy could provide some clarification. Suppose you disrupted your diet by increasing caloric intake by 1,095%, or 297% or even 37%. Would this be a significant disruption to your system? This may not be a perfect analogy, but it puts the magnitude of the changes somewhat in perspective. With these increases in nutrient loading then, it would not be reasonable to discount the potential impacts upon the associated ecosystems, including downgradient areas such as Hart Prairie and off-site groundwater resources. Therefore additional testing and monitoring is essential to determine the presence of effluent and effluent residuals both within the SnowBowl Subarea and in downgradient regions, and an attendant monitoring of indicators of ecosystem changes including recording of transects to determine vegetational changes and tracking any changes in associated fauna. Initial testing could provide indication of the presence and movement of the effluent and effluent residuals, with a more comprehensive long-term program to identify specific trends and impacts.