REPORT

Remediation for the Environment of the Po River Territory

Group 1

Allyson Klabunde, Shayla Kapoor, Annalisa Franceschini, Lucia Paye-Layleh, Azza Aldaria

UAPP411/611: Regional Watershed Management

Dr. Gerald Kauffman

April 25th, 2025

Mission Statement

REPORT's goal is to analyze the environmental and anthropogenic stressors within the Ro River Watershed and provide recommendations for reducing these effects on this vital Swiss and Northern Italian watershed. Through these recommendations, we hope to decrease nitrogen pollution by 30%, reduce groundwater pumping by 30%, and increase vegetation by 50% to make it environmentally and economically sustainable by 2035. The Po River serves as a key economic, agricultural, navigation, and recreation driver of the region, which we aim to maintain and sustain in the future.

Background

Geographical Context:

Po River, the longest river in Italy, rises in the Monte Viso group of the Cottian Alps on Italy's western frontier and empties into the Adriatic Sea in the east after a course of 405 miles (652 km). The river has a Latitude: 44° 58' 7.19" N and a Longitude: 12° 32' 29.39" E. Flowing eastward in its upper course, the Po is rapid and precipitous. The Po forms the boundary between the regions of Lombardy and Emilia-Romagna (south) and Veneto (north). It receives the waters of the Dora Riparia and the Dora Baltea below Turin; other principal tributaries are the Sesia, Ticino, Adda, Oglio, and Mincio from the north. The river flows through many important Italian cities, including Turin, Piacenza, Cremona, and Ferrara.

The Po has a drainage area of 74,000 km^2, 70,000 is in Italy, of which 41,000 is in montane environments and 29,000 on the plain. Almost all of the non-Italian basin is in Switzerland. The landscape surrounding the Po River in Italy is characterized by a vast, fertile plain known as the Po Valley or Po Basin. The delta of the Po River, where it empties into the

Adriatic Sea, is also a unique landscape with various natural habitats, including forests, lagoons, and wetlands. The slope of the Po's river valley decreases from 0.35% in the west to 0.14% in the east, a low gradient. The Po River's gradient, or slope, decreases from its source to its mouth.

Physical Characteristics of the River

The Po River's channel morphology exhibits characteristics of both meandering and braided streams, with varying channel widths and depths. The river's average width in a specific reach is about 267 meters, while the low-discharge bed is a mix of sand and gravel. The river also shows a sinuosity (meandering) of less than 1.5.

The Po River in Italy features diverse riverbanks, from the rugged terrain of the Alps in its upper reaches to the fertile plains and delta in its lower course. Natural levees and meandering channels have shaped the riverbanks, leading to the formation of oxbow lakes and a complex delta system at its mouth. The Po River features several prominent islands, sandbars, and tributaries. Human activities, including agriculture and urban development, have also impacted the riverbanks, leading to the construction of dikes and canals for flood control and water management.

Water Quality and Composition:

The pH of the Po River water generally falls between 7 and 8, indicating slightly alkaline conditions. Water temperature can range from 22-32°C depending on the season. Dissolved oxygen levels are influenced by temperature, with higher temperatures typically resulting in lower dissolved oxygen concentrations. The Po River's hydrological cycle is influenced by snowmelt from the Alps and Apennines, resulting in a mixed discharge regime with two periods of flooding (spring and fall) and two periods of low water (winter and summer).The river's

annual average flow is around 1,510 m^3/s at Pontelagoscuro. It also experiences droughts and periods of high flow due to natural variations and human activities.

The Po River in Italy faces significant challenges from deforestation, damming, and pollution, including organic pollutants like pesticides and herbicides, heavy metals, and nutrient pollution from agricultural runoff, impacting its health and the surrounding environment. Industrial waste, sewage discharge, and plastic pollution also contribute to the river's contamination. The Po River carries significant amounts of sediment and organic matter, along with other substances, into the Adriatic Sea. The river also transports trace metals like nickel and chromium, likely from the ultramafic rocks in its catchment area, to the Adriatic Sea.

Biological Diversity:

The Po River supports a diverse range of aquatic life, including various fish species, invertebrates, aquatic insects, and plants. It's a significant freshwater ecosystem with both native and non-native species, including endangered and invasive species inhabiting its waters. Endangered species in the Po River Basin include the Po brook lamprey, South European nase, and Italian nase. Invasive species, like the Wels catfish, have also established populations in the river and are impacting native fish populations.

The Po River's ecological health is facing significant challenges, particularly related to eutrophication and climate change. While some levels of pollution have been reduced, issues like excessive nutrient runoff and drought are impacting the river and its ecosystem. The river's healthy ecosystem is important for a variety of organisms, including birds, mammals, and insects.

Human Activities and Ecological Factors

The Po River is used for a variety of human purposes, including agriculture, industry, power generation, transportation, and recreation. It is a vital source of water for irrigation, supports a major industrial area, and provides hydroelectric power. Water infrastructure projects like dams, canals, and flood control systems have significantly impacted the river and its surrounding areas. These projects have facilitated hydroelectric power, supported agriculture in the Po Valley, and helped manage river flows for various purposes. The vast valley around the Po is called the Po Basin or Po Valley (Italian *Pianura Padana* or *Val Padana*), the main industrial area and the largest agricultural area in the country, accounting for 35% of Italian agricultural production. The industrial centres, such as Turin and Milan, are located on higher terrain, away from the river. They rely for power on the numerous hydroelectric stations in or on the flanks of the Alps, and on the coal/oil power stations which use the water of the Po basin as coolant. In 2002, more than 16 million people lived in the area, at the time nearly one-third of the population of Italy. The Po has 141 tributaries.

The "Renaturation of the Po River area" project is a large-scale restoration effort led by the Interregional Agency for the Po River (AIPo) and supported by the Italian National Recovery and Resilience Plan (PNRR). This initiative aims to restore the Po River's natural course, improve the ecosystem, and enhance the quality of life for residents and tourists. The project encompasses various interventions, including ecological and environmental restoration, reactivation of oxbow lakes and abandoned branches, natural reforestation, and adjustment of navigation groins. The river supports a rich biodiversity, faces threats like pollution and habitat alterations, and is crucial for regional biodiversity conservation.

Policies

To protect the Po River, several agencies and policies have been established to regulate what needs to be done to keep the river healthy. One of the major pieces of legislation is the "Renaturation of the Po area" (PNRR), with its primary responsibility to restore, preserve, and protect biodiversity, safety and quality of life for people and wildlife. The project is divided into 56 intervention areas distributed along the entire Po River, with some ecological and environmental restoration interventions being reactivating oxbow lakes, abandoned branches, and natural reforestation to consolidate and expand the existing forests, lowering the river bed to be overcome of the ordinary rates of the Po, and containing invasive alien plant species. The project's start date was 16 November 2021, and the date of completion is 31 March 2026.

In 1989, Law 183 established the river basin as "the basic unit within which all regulatory actions concerning water resource management, water pollution control and soil protection were to be coordinated for economic and social development and for environmental protection. The law also established major basin authorities and entrusted them with planning responsibilities." (PO Basin Authority, 2016). With the implementation of Law 183, the Po River Basin Authority was thus created, along with five other national river basin authorities. The ADBPO's main activities are but are not limited to include environmental monitoring, cost-benefit analysis on realized interventions, and territorial and socio-economic data collection, management and spreading.

Finally, the WWF (World Wildlife Fund), Italian Aggregate Association, and Interregional Agency for the Po (AIPO) all support the Po River Basin Authority by designing

and funding a €357 restoration project. This project aims to ‘restore’ 44 areas in the middle reaches of the river and the delta, including restoring 1,500 hectares of wetlands and 340 hectares of forest, reopening oxbow lakes, lowering navigation groynes, and controlling invasive alien plants. The AIPO is a public body that provides environmental and engineering services in full interest of the Italian regions crossed by the Po River (Emilia, Piemonte, Lombardia, Romagna, and Veneto). In addition, in 2007, the AIPo and ARNI (Regional Agency for Inland Navigation for Emilia – Romana) drew up a collaborative agreement for project coordination and planning. More recently, the Po Media River Contract was signed into action on November 6th, 2024, and it includes a total of 34 municipalities and aims to “protect and enhance the proper management of water resources made available by the longest river in Italy.” (Sogin and the Emilia-Romagna Region Sign an Agreement on Environmental Compensation, 2025). This agreement is also focused on balancing environmental measures and promoting further agreements between Sogin and the local administrations concerned.

These policies and agencies in place are essential to ensure that powerful international governments cannot deplete these natural resources and land that millions of people in the Po River depend on for survival. Without them, groundwater pumping, deforestation, and wetlands would be much more likely to become destroyed and cause detrimental effects to the environment, not just in the Po River but in the surrounding areas as well, impacting thousands more civilians.

Problems

Problem	Description	Causes
P1: Nutrient Pollution	High nutrient levels in the Po River watershed lead to eutrophication of the Northern Adriatic Sea. High nutrient levels pose threats to aquatic life in the Po River watershed and the Adriatic Sea.	About 41% of the Po River land is used for agriculture, leading to high Nitrogen and Phosphorus levels within the watershed. The use of livestock manure, mineral fertilizers contributes up to 85% nitrogen in the Po River. High phosphorus levels are correlated with dairy farms, traditional farms, and pig farms.
P2: Drought	The Po River demonstrates a trend of worsening drought conditions over time.	Precipitation decline and corresponding declines in snow fraction and snowmelt are leading to lower flow. Increasing evaporation rates. Increased surface water withdrawals, particularly associated with irrigation, are lower water levels in the Po River. Withdrawals have increased sizably since 1900, from 0.86 million ha up to 1.63 million ha in 2015.
P3: Saltwater Intrusion	Threats of saltwater intrusion have become severe in recent years.	A range of factors, including pumping of groundwater, the reduced flow of the river due to damming and irrigation, and rising sea level, have been attributed to this.

Problem 1: Nutrient Pollution:

The Po River basin(northern Italy), one of the most agriculturally exploited and densely populated areas in Europe. It is heavily polluted, particularly with nutrients, organic matter, and industrial chemicals. Major sources of nutrients, especially nitrogen and phosphorus, contribute to the severe marine eutrophication problems in coastal lagoons and the Adriatic Sea. Eutrophication can lead to a decline in water quality, oxygen depletion, and harm to aquatic life. This nutrient pollution is primarily driven by agricultural runoff, industrial discharges, and wastewater.

About 41% of the Po River basin is used for agriculture, and agriculture and livestock collectively contribute about 80% of the total nitrogen load in the basin. High levels of nitrates, particularly in the lower Piedmontese plain and Emilia-Romagna plain, are a major concern. Climate change, including alterations in precipitation and temperature, is exacerbating eutrophication by affecting nutrient removal and recycling processes.

Concentration and flows of nitrogen compounds in freshwaters associated with agriculture have increased 2-3 fold during the last decades in the Po basin (Viaroli et al., 2018). Nitrogen pollution processes from croplands to streams and aquifers can be classified in three groups: 1) winter and spring flows from upland rainfed cereal cropping systems, 2) percolation flows directly to aquifers from irrigated areas (mostly alluvial; Aschonitis et al., 2013), and 3) irrigation return flows.

Areas with high livestock density are associated with high nitrogen pollution due to the over-application of manure on croplands. The application of livestock manure (pig, poultry, and cattle) together with mineral fertilizers largely exceeds crop uptake, contributing to 85% of

nitrogen reaching aquifers (Mantovi et al., 2006; Bartoli et al., 2012; Perego et al., 2012; Lasagna and De Luca, 2019). Leaching from maize is very severe, and 80% of surplus can be leached (Perego et al., 2012) with a higher risk in the low-yield areas. Anyhow, there is high territorial diversity, and in some areas, such as the Volta basin in Po, good fertilization practices and the upward movement of nitrogen towards the root zone may significantly reduce nitrate leaching (Ventura et al., 2008; Morari et al., 2012). Nitrate leaching in rice is much less severe (Zavattaro et al., 2006). Nitrate leaching in rice is much less severe unless boosted by salt crust formation, like in some areas of the Po delta (Colombani et al., 2016)..

Phosphorus surplus has been less researched, but studies showed that the drivers controlling phosphorus pollution are 1) the type and amount of fertilization and 2) soil characteristics (Borda et al., 2010; 2011).. Maxima phosphorus surpluses originated in dairy farms, traditional farms, and pig farms. Phosphorus fertilization can, in general, be significantly reduced (Castoldi et al., 2009), also in rice fields (Zavattaro et al., 2006)..

Goal 1:

The Po River's excess nutrients, especially nitrogen, have caused real concern for the river's health and watershed. Three responses could be effective in mitigating this issue. First, implement optimized fertilization techniques on the region's agricultural land. Optimized fertilization includes a handful of techniques, not limited to slow release, the decreased use of fertilizers, and the use of straw. These each aim to decrease the use of fertilization and yet make fertilization more efficient. Slow-release fertilization can be done in different ways, we recommend using Soltellus Polymers, which bind to the soil and allow the nutrients to escape

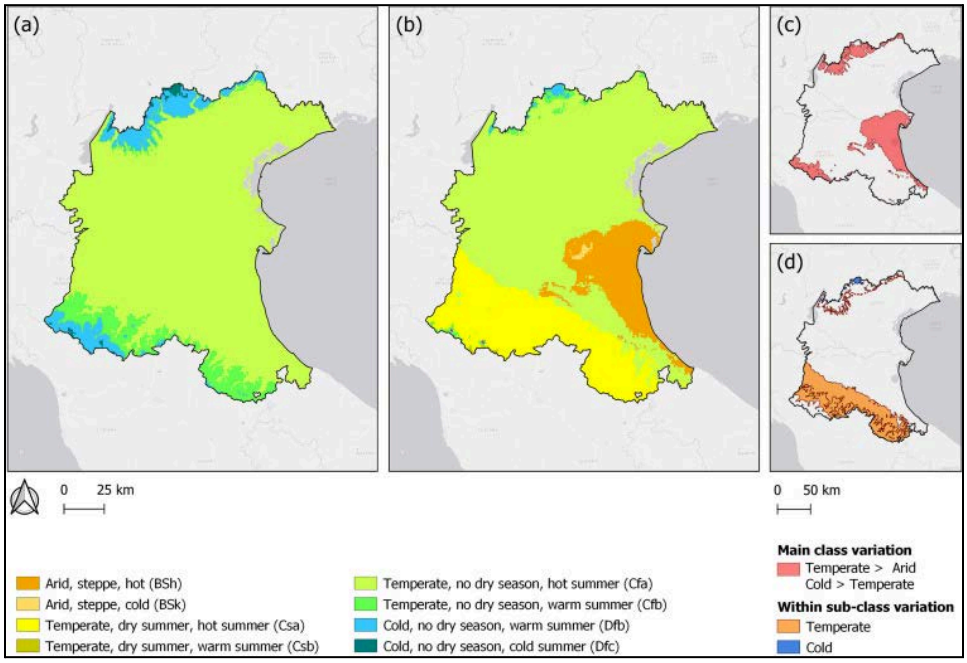
over a 24- 50 day period (Cheny, 2023). Thus allowing the plants to absorb the nutrients without the loss from runoff. This would benefit both farmers and the watershed.

Secondly, the use of zeolite rock as a soil amendment can reduce the amount of water and nitrogen being lost in runoff as well. Zeolite rock is a substance that is renowned for its ability to absorb water and nutrients when in abundance and to release water and nutrients during times of scarcity (Cheny, 2023). Unlike other nutrient absorbers like lime, these rocks do not decompose over time and thus can be left without additional attention for a much longer period than alternatives (Cheny, 2023). This addresses a need for both farmers and the watershed while being price-conscious. A grant for one year of implementation would be easier than a project requiring yearly additives, making it easier to implement and for farmers to be supportive of.

Finally, the livestock farmers of the region can use compost systems to control their contribution to accessing nitrogen in the watershed. These systems vary in size and type of farm; however, they generally require an impervious floor, walls, a cover from rain, and a pipe aerating the compost (*Like All the Best Solutions, Aerated Composting Is Really Quite Simple)*. That allows the manure to fully pasteurize and no longer pose a threat of having excess nutrients run off into the watershed. This is similar to the grant situation as the zeolite rock, which allows the policy to be relatively affordable for the government and farmers.

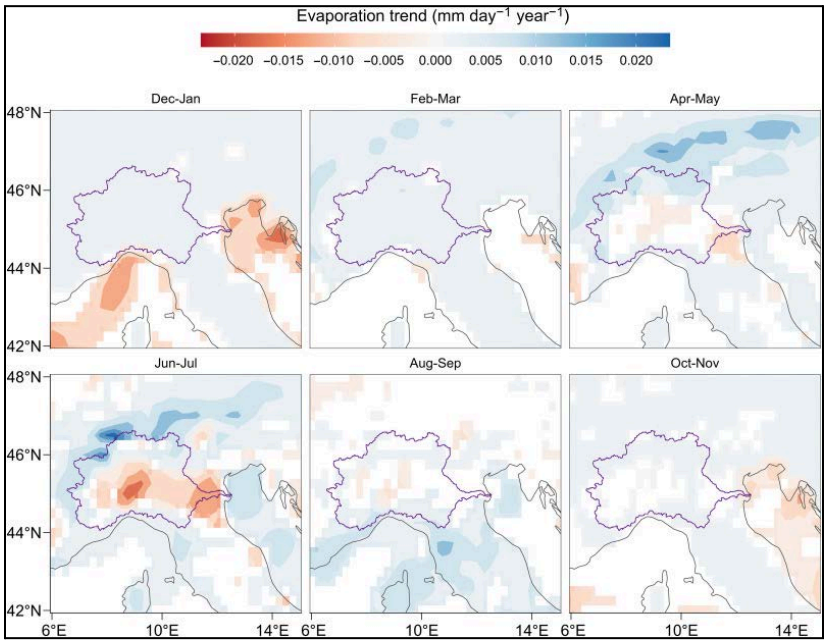
Problem 2: Drought

Drought in the Po River Watershed comes from numerous factors that work in conjunction to develop serious environmental challenges that negatively impact the agricultural sector and the ecological health of Northern Italy. Increasing temperature and lowering precipitation trends lead to drought and lower flow throughout the river, particularly in the summer months. In the summer season, the average rainfall throughout 2009-2021 decreased by 31% compared to data from 1994-2008 (Straffelini et al., 2023). The climate of the region is becoming increasingly arid, which can pose significant challenges for agriculture in the region as climate conditions change in the future. The region is primarily classified as Temperate (91% of the total land), specifically as having no dry seas and hot summer/ warm summers. If it is predicted in the future (2070-2100), the region will drop to 85% Temperate, and areas classified as arid will expand (Straffelini et al., 2023).



Climate maps modified from Beck et al. (2018) for the study area. (a) Present climate zones. (b) Future climate zones (2071 > 2100; RCP8.5 scenario). (c) Areas subject to the main climate class change. (d) Areas subject to sub-climate class variation. (Straffelini et al., 2023)

The increasing temperatures are also leading to earlier snowmelt, and the spring season is now seeing higher-than-average flow, which further exacerbates the drought conditions in the summer months (Straffelini et al., 2023) (Montanari et al., 2023). Additionally, the high temperatures are leading to increased surface evaporation throughout the watershed. From 1940 to 2022, there has been an upward trend in the amount of evaporation in the watershed with a +0.013 km3 year−1 (P = 0.01) upward trend (Montanari et al., 2023).



Evaporation trend estimation for the period 1940–2022 from ERA5 Reanalysis bimonthly data (23). Only significant trends (P < 0.1) are shown. The Po River basin boundary is shown in purple. (Montanari et al., 2023).

Overall climate climate-related changes are leading to drier drought conditions in the Po River Watershed, which pose an increased risk to the natural function of the resources and disrupt usage in the watershed.

The Po River is vitally important for the agricultural sector within the region and accounts for around 40% of Italy's food resources (Edwards, 2022), however, the agricultural

sector is disproportionately responsible for the degradation, over-exploitation of the Po River, and heavily contributes to the drought conditions. High quantities of groundwater withdrawals, partially for the agricultural sector, and inefficient use of water resources are liable to worsen the problem. Agriculture accounts for around 80 percent of water withdrawals within the basin (Edwards, 2022). Water-intensive crops, such as rice and tomatoes, are common throughout the regions, along with water-intensive livestock demands place pressure on the water resources. Water withdrawals have also been increasing over the past century to meet the growing food demand, but at a cost to the river. In addition surface and furrow irrigation (Edwards, 2022) are the most common agricultural methods throughout the regions, which are some of the most inefficient methods, leading to a lot of water loss.

In addition to the inefficient irrigation methods, water infrastructure distribution systems are prone to high rates of leakage. During the record-breaking 2022 drought of the Po River in the five regions in which a water-related state of emergency was declared, their water leakage rates were 26.3%, 25.4%, 32.1%, 37.8%, and 45.0% of their treated drinking water. The World Bank reports that in most developing countries, the average is 15% (Edwards, 2022). The Po River is experiencing significantly high leakage rates, which worsen the water and drought conditions.

Goal 2:

The main issue related to drought conditions on the Po River relates to inefficient agricultural usage and climate-related problems. Due to the pressing nature of these issues, the effect of the condition is worsening. We recommend immediate action by the agricultural sector to lessen its impact on the river. Farms should transition their crops to less water-intensive crops and invest in improved irrigation methods, such as drip irrigation. While recommending action

by farmers and agricultural stakeholders REPORT also values ensuring this is a collaborative process involving the input and needs of the farmers within the region. Plans, timelines, and actions will be implemented with the involvement and contributions from farmers to ensure the most success for these plans. We also recommend public education initiatives to keep stakeholders and users informed about the changing cognition and vulnerability of the watershed. The public needs to remain informed about their consumption habits to ensure responsible use, particularly in the summer months.

Problem 3: Saltwater Intrusion

As drought becomes more frequent in the Po River, saltwater intrusion is a direct result and causes drastic impacts to the quality of the water, agriculture, and coastal plants. Excessive groundwater pumping, sea level rise due to climate change, and reduced flow of the river are the primary reasons why saltwater intrusion is becoming more frequent in the Po River. In the past two decades, six episodes of drought have occurred. The average discharge of the river was about 1500 m3 s-1, which favors the saltwater intrusion along the tributaries of the delta up to many kilometers from the sea. In all of these episodes, the recorded water salinity was more than 2 g/l, the critical threshold FAO indicated for irrigation. (PLOS Water). During the summer of 2022, the height of the drought, much of the surface of the Po River Delta was exposed to saltwater intrusion, with water salinity peaks in July when the discharge reached the negative record of 104 m3s-1 at Pontelagoscuro. Critical salinity levels of river water were recorded up to about 40 km upstream of the sea along the main river course and a principal branch of the Po River (Po Di Goro). The drought of 2022 is claimed to be worse than the severe drought that

occurred in 2006 in the Po River, which was recognized as one of the most challenging droughts with critical salinity up to 30 km from the sea.

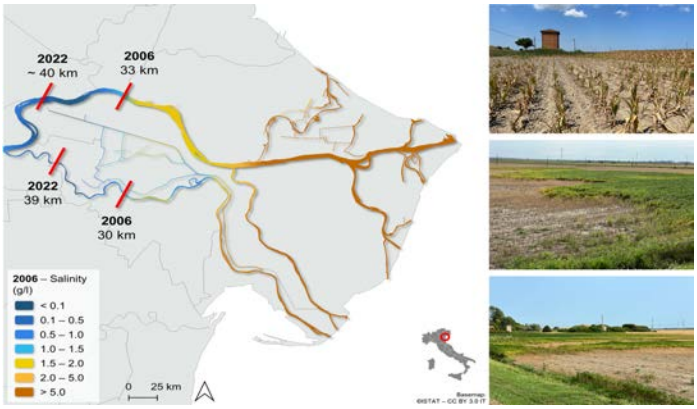


Fig 1. Saltwater intrusion in the Po River Delta during the two major droughts of the summer of 2006 and 2022.

Saltwater intrusion is becoming more prominent in the Po River as groundwater pumping increases, sea level rises, and the drought reduces the flow of the river. Farmers, aquatic life, and the individuals who live in the Po River Basin suffer greatly from these changes in salinity, as it is harder for animals and humans to adapt to these changes. Freshwater is a primary resource of the entire agricultural landscape of the delta, which is used for irrigation through a capillary canal network. It is also an essential resource for the 17 million people who rely on freshwater in the Po River. To remove saltwater that has contaminated freshwater, it is a lengthy process and, most importantly, costly. For farmers, their crops have been severely impacted by saltwater intrusion, as they are not able to survive with these new levels, ultimately killing off the potential profit the farmers could have made.

Goal 3:

By 2035, we aim to reduce groundwater pumping in/near the river by 30%. By doing this, coastal and agricultural areas will hopefully suffer less from excessive saltwater intrusion, and soil fertility/crops can thrive. To achieve this goal, we plan to promote surface water irrigation (which will also increase aquifer recharge), encourage better surface water management, and

address the impacts of climate change. Augmentation is one way to increase the water supply by replacing the current reduced amount of water from groundwater pumping. This can be done through active recharge of water sources and protection of water recharge areas. Another approach is to build artificial subsurface barriers, such as cutoff walls or subsurface dams, to prevent saltwater from moving inland. However, this solution will not be as effective as finding ways to replenish the water because, as sea level rises, the barriers might eventually give out due to new conditions and ultimately cause more harm than good.

Through these potential solutions to achieve our goal by 2035, we hope to improve the water quality for the individuals living there who depend on the water, farmers who require freshwater for healthy crops, and coastal land with aquatic life that cannot survive if saltwater intrusion is not addressed in the Po River Delta.

Recommendations

1. To control nitrogen levels within the watershed, implement optimized fertilization techniques, use zeolite rock as a soil amendment, and use compost systems on agricultural lands.

Nitrogen levels within the Po River watershed are of great concern to the health and viability of the Po River and need urgent addressing. Implementing these techniques to control and limit nitrogen pollution in the river is needed. Implementing these programs should be done quickly and economic incentives should be offered to encourage adoption.

2. Transition agriculture crops from water-intensive crops to less water-intensive crops that are more reflective of the natural environment and improve the water distribution infrastructure to limit water loss in an effort to address lowering water levels in the Po River.

Drought conditions and lowering water levels within the Po River watershed are affecting the economic opportunity and ecological health of the river and need immediate action along with long-term initiatives to improve the watershed health.

Saltwater intrusion in the watershed is a pressing issue, but steps are available to lower the potential threat.

3. Reducing groundwater pumping in/near the river by 30% by 2035. This was achieved by promoting surface water irrigation and improved surface water management.

Ensure the public remains educated on watershed health, conservation techniques, and potential risks facing the watershed. This will allow watershed users to gain knowledge about their waterways and promote smart usage.

4. Encourage Public Education
5. Regular Performance Evaluation:

Set up a monitoring protocol that checks for breakthrough times, pressure drops, and media degradation to ensure sustained performance and preempt failures. This will allow for the long-term success of the REPORT. Involving local and regional stakeholders within the continuous monitoring and reevaluation process is also recommended to ensure local knowledge and needs are also met.

Conclusion

The Po River serves as a key economic and agricultural resource for Northern Italy, but is under current threat from over-exploitation and climate change. Taking immediate and sustained long term action is needed to ensure the health of this vital waterway is needed. Nutrient Pollution, Drought, and Saltwater Intrusion are the key challenges facing the Po River, all of which are interconnected and require integrated solutions. Solutions and action taken on the Po

River should always involve key local stakeholders, expert knowledge and continuous monitoring and evaluation to ensure the goals are upheld and targeted as conditions change in the watershed. The agriculture sector will need to make the most concerted changes to their practices as one of the key conditions to the watershed deterioration, but this is achievable through offering incentive programs and ensuring the public remains knowledgeable on their water rescues. The Po River is a beautiful, diverse, and highly important watershed that REPORT is determined to sustain.

Source

Aschonitis, V. G., Salemi, E., Colombani, N., Castaldelli, G., Mastrocicco, M. 2013. Formulation of Indices to Describe Intrinsic Nitrogen Transformation Rates for the Implementation of Best Management Practices in Agricultural Lands. Water Air and Soil Pollution 224, 1489, doi: 10.1007/s11270-013-1489-1

Bartoli, M., Racchetti, E., Delconte, C.A., Sacchi, E., Soana, E., Laini, A., Longhi, D., Viaroli, P. 2012. Nitrogen balance and fate in a heavily impacted watershed (Oglio River, Northern Italy): in quest of the missing sources and sinks. Biogeosciences 9, 361-373, doi: 10.5194/bg-9-361-2012

Basso, B. et al. 2012. Environmental and economic evaluation of N fertilizer rates in a maize crop in Italy: A spatial and temporal analysis using crop models. Biosystems Engineering 113, 103-111, doi: 10.1016/j.biosystemseng.2012.06.012

Borda, T., Withers, P. J. A., Sacco, D., Zavattaro, L., Barberis, E. 2010. Predicting mobilization of suspended sediments and phosphorus from soil properties: a case study from the north west Po valley, Piemonte, Italy. Soil Use and Management 26, 310-319, doi: 10.1111/j.1475-2743.2010.00281.x

Borda, T., Celi, L., Zavattaro, L., Sacco, D., Barberis, E. 2011. Effect of agronomic management on risk of suspended solids and phosphorus losses from soil to waters. Journal of Soils and Sediments 11, 440-451, doi: 10.1007/s11368-010-0327-y

Castoldi, N., Bechini, L., Stein, A. 2009. Evaluation of the spatial uncertainty of agro-ecological assessments at the regional scale: The phosphorus indicator in northern Italy. Ecological Indicators 9, 902-912, doi: 10.1016/j.ecolind.2008.10.009

Colombani, N., Di Giuseppe, D., Faccini, B., Mastrocicco, M., Coltorti, M. 2016. Formation and dissolution of salt crusts as a rapid way of nitrate mobilization in a tile-drained agricultural field under a temperate climate. Arabian Journal of Geosciences 9, 463, doi:10.1007/s12517-016-2473-z

Colombani, N., Di Giuseppe, D., Faccini, B., Mastrocicco, M., Coltorti, M. 2016. Formation and dissolution of salt crusts as a rapid way of nitrate mobilization in a tile-drained agricultural field under a temperate climate. Arabian Journal of Geosciences 9, 463, doi:10.1007/s12517-016-2473-z

Edwards, E. (200) Climate Change - a scapegoat or driver for the Po River's downfall? Water Science Policy. https://doi.org/10.53014/LIYB5095

English presentation | AIPO - Agenzia Interregionale per il fiume PO. (2021). Agenziapo.it. https://www.agenziapo.it/content/english-presentation

Colombani, N., Di Giuseppe, D., Faccini, B., Mastrocicco, M., Coltorti, M. 2016. Formation and dissolution of salt crusts as a rapid way of nitrate mobilization in a tile-drained agricultural field under a temperate climate. Arabian Journal of Geosciences 9, 463, doi:10.1007/s12517-016-2473-z

Lasagna, M., De Luca, D.A. 2019. Evaluation of sources and fate of nitrates in the western Po plain groundwater (Italy) using nitrogen and boron isotopes. Environmental Science and Pollution Research 26, 2089-2104, doi: 10.1007/s11356-017-0792-6

Mantovi, P., Fumagalli, L., Beretta, G. P., Guermandi, M. 2006. Nitrate leaching through the unsaturated zone following pig slurry applications. Journal of Hydrology 316, 195-212, doi: 10.1016/j.jhydrol.2005.04.026

Montanari, A., Nguyen, H., Rubinetti, S., Ceola, S., Galelli, S., Rubino, A., & Zanchettin, D. (2023). Why the 2022 Po River drought is the worst in the past two centuries. Science Advances, 9(32), eadg8304–eadg8304. https://doi.org/10.1126/sciadv.adg8304

Morari, F., Lugato, E., Polese, R., Berti, A., Giardini, L. 2012. Nitrate concentrations in groundwater under contrasting agricultural management practices in the low plains of Italy. Agriculture Ecosystems & Environment 147, 47-56, doi: 10.1016/j.agee.2011.03.001

Perego, A., et al. 2012. Nitrate leaching under maize cropping systems in Po Valley (Italy). Agriculture Ecosystems & Environment 147, 57-65, doi: 10.1016/j.agee.2011.06.014

"Renaturation of the Po River area" PNRR - National Recovery and Resilience Plan. Italy | Department of Economic and Social Affairs. (n.d.). Sdgs.un.org. https://sdgs.un.org/partnerships/renaturation-po-river-area-pnrr-national-recovery-and-resilience-plan-italy

Straffelini, E., & Tarolli, P. (2023). Climate change-induced aridity is affecting agriculture in Northeast Italy. (G. Martin, Ed.).Agriculture Systems, 208. https://www.sciencedirect.com/science/article/pii/S0308521X23000525

Ventura, M., et al. 2008. Nitrogen balance and losses through drainage waters in an agricultural watershed of the Po Valley (Italy). European Journal of Agronomy 29, 108-115, doi: 10.1016/j.eja.2008.05.002

Viaroli, P., et al. 2018. Space and time variations of watershed N and P budgets and their relationships with reactive N and P loadings in a heavily impacted river basin (Po river, Northern Italy). Science of the Total Environment 639, 1574-1587, doi: 10.1016/j.scitotenv.2018.05.233

Zavattaro, L., Romani, M., Sacco, D., Bassanino, M., Grignani, C. 2006. Fertilization management of paddy fields in Piedmont (NW Italy) and its effects on the soil and water quality. Paddy and Water Environment 4, 61-66, doi: 10.1007/s10333-005-0029-z